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ADVANCED SIMULATOR FOR PILOT TRAINING: DESIGN OF AUTOMATED PERFORMANCE MEASUREMENT SYSTEM

By

John H. Fuller
Wayne L. Waag
Elizabeth L. Martin

OPERATIONS TRAINING DIVISION
Williams Air Force Base, Arizona 85224

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This technical report has been reviewed and is approved for publication.

DIRK C. PRATHER, Lieutenant Colonel, USAF
Technical Advisor, Operations Training Division

RONALD W. TERRY, Colonel, USAF
Commander

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The objective of this effort was to design and implement an automated performance measurement (APM) system in the Advanced Simulator for Pilot Training (ASPT). This report documents that development effort and describes the current status of the measurement system. It was assumed that superior flying performance in the aircraft or the simulator has several characteristics which are reflected by available flight parameters. These include (a) maintaining certain aircraft state parameters, such as airspeed or altitude, close to some defined criterion value, (b) avoding excessive rates and acceleration forces so that the maneuver is executed smoothly, (c) accomplishing these objectives with the least amount of effort; that is, by minimizing control inputs, and (d) not exceeding procedural or safety limits established for the maneuver.

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To date, the following scenarios have been implemented on the ASPT: (a) ~~Transition~~ Tasks — Straight and Level, Airspeed Changes, Turns, Climbs/Descents; (b) Takeoff/Approach/Landing Tasks — Takeoffs, Tech Order Climbs, Slow Flight, Configuration Changes, Straight-in Approaches, Overhead Patterns, Touch-and-Go's; (c) Instrument Tasks — Rate Climbs/Descents, Vertical S-A, Vertical S-D, GCA, Proceed Direct to VOR; (d) Aerobatics — Aileron Rolls, Barrel Roll, Loop, Split S, Cloverleaf, Cuban 8, Lazy 8; and (e) Formation — Fingertip. This measurement capability has been subsequently utilized in numerous training research studies. The generalizability of the measurement approach has been demonstrated in recent modifications of many of the scenarios for use by the ASPT in an A-10 aircraft configuration. Such generality points to the possibility of developing standardized measurement scenarios applicable to a wide variety of aircraft and simulator types.

PREFACE

This report represents a portion of the research program of Project 1123, USAF Flying Training Development, Mr. James F. Smith, Project Scientist; Task 112301, Development of Performance Measurement Techniques for Air Force Flying Training, Dr. Elizabeth L. Martin, Task Scientist. This study was conducted and supported by the staff of the Flying Training Division of the Air Force Human Resources Laboratory.

The authors would like to express appreciation to a number of individuals who assisted in various parts of this effort. Maj Robert R. Fuller wrote the initial preprogramming software packages for the first scenarios that were developed. Mr. Lynn Thompson continued the effort and completed most of the existing software. Mr. Bill Hopkins completed initial work on the Student Data System. Refinements to the Student Data System and development of the retrieval and analysis software were completed by Mr. Terry Templeton. Capt Ed Chun converted much of the measurement software as a result of a major computer configuration change in the ASPT. Ms. Valerie Bowes performed a software validation of all measurement scenarios.

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ADVANCED SIMULATOR FOR PILOT TRAINING: PERFORMANCE MEASUREMENT SYSTEM

I. INTRODUCTION

The Advanced Simulator for Pilot Training (ASPT) was developed to be a research tool capable of providing answers to questions concerning the design and effective utilization of advanced flight simulators. It was designed to simulate the T-37 aircraft, the primary jet trainer used by the Air Force. The ASPT consisted of two cockpits, each with a full field-of-view (FOV) visual scene, a six-degrees-of-freedom synergistic platform motion system, and a 16-panel pneumatic G-seat. Also included were state-of-the-art training features, such as prerecorded demonstrations, record/playback, freeze/initialization, and graphic feedback displays. A detailed description of the ASPT may be found in Gum, Albery, and Basinger (1975).

Despite the sophistication of the ASPT and its research potential, one significant ingredient was lacking—an objective pilot performance measurement system. The development and implementation of an Automated Performance Measurement (APM) system became one of the priority efforts within the Air Force Human Resources Laboratory since such a capability would become the foundation of future research to be accomplished in the device. This report attempts to document that development effort and present the current status of the measurement system.

II. APPROACH

Background

The importance of the measurement problem has long been realized within the Air Force flying training research community. Early work at the Air Force Personnel and Training Research Center (AFPTRC) focused on the development of objective scoring procedures for use in the T-6 aircraft. Smith, Flexman, and Houston (1952) developed Performance Record Sheets for in-flight use on which the instructor was required to record specific events for each maneuver, such as maximum airspeed, altitude loss, etc. These Performance Record Sheets were subsequently used to collect data on student performance in an attempt to develop objective performance standards (Houston, Smith & Flexman, 1954). Other efforts at AFPTRC focused on the use of motion pictures for recording of cockpit instruments during various flight maneuvers and the use of such data to generate measures of performance.

The establishment of the Air Force Human Resources Laboratory in 1968 again resulted in efforts aimed at the development of objective measures of pilot performance. By this time, computer technology had advanced to the point of allowing the rapid processing of large amounts of data. The capability of recording objective flight parameters in both the flight simulator and the aircraft led to efforts to develop measures of pilot performance using fairly elaborate computational and statistical procedures.

The statistical approach to measurement development was explored in a series of studies attempting to develop automated proficiency measures in the Link General Aviation Trainer GAT-1 (Hill & Eddowes, 1973; Hill & Goebel, 1971). Three categories of experience level were defined

according to the number of flying hours. Continuous parameters were recorded on a series of simulated flying tasks. From these, a total of 326 measures were generated for the first study and 2,436 for the second. In each case, 30 subjects were used, 10 within each of three levels of flying experience (beginner, intermediate, and advanced). Attempts to cross-validate the findings from Study I to Study II demonstrated a failure to meet the assumptions required in the statistical analyses. While the statistical approach represents one possible way of selecting measures which discriminate among pilots of varying experience levels, in many cases, it is simply infeasible. The required subject-to-variable ratio often makes the approach prohibitive. To realistically evaluate the predictive validity of the 326 variables in the first study would have required a minimum of over 1,300 subjects. To employ the statistical approach effectively requires that the assumptions of the analysis technique be met.

A series of studies was completed which attempted to develop and validate pilot proficiency measures using data collected in an instrumented T-37 aircraft. Two alternative approaches to measurement development were evaluated. The first approach (Connelly, Bourne, Loental, & Knoop, 1974a) attempted to use the computer to generate candidate measures which would subsequently be tested to determine their validity. The steps included (a) maneuver segmentation, (b) development of reference functions (desired flight path), and (c) application of adaptive math models. Unfortunately, insufficient aircraft data were available for a validation of the approach. The second approach (Connelly, Bourne, Loental, Migliaccio, Burchick, & Knoop, 1974b) used the researcher (as opposed to the computer) to develop candidate performance measures which would subsequently be tested to determine their validity. Again, insufficient data prevented a validation.

In preparation for the delivery of the ASPT, Baum, Smith and Goebel, (1973) analyzed six maneuvers trained in the T-37 aircraft. Included were maneuver descriptions, critical parameters, standards for each parameter, and a rank ordering of difficulty. Waag, Eddowes, Fuller, and Fuller (1975) then developed and implemented scenarios for selected basic instrument maneuvers on the ASPT. (This effort occurred before installation of the visual system so that no contact tasks could be flown.) Upon completion, of the implementation on ASPT, subjects of differing experience levels flew the scenarios while being evaluated by experienced instructor pilots (IPs). An analysis of the data revealed (a) the agreement between raters was high, (b) the objectively derived measures predicted the IP ratings quite well, and (c) the objective measures discriminated between naive and experienced pilots. Encouraged by these findings, an effort was initiated to develop measurement scenarios for representative tasks of all phases of T-37 training. This report documents that effort.

Measurement Requirements

At the outset, there were certain constraints placed on the development effort. As indicated earlier, the ASPT was designed to be a research tool. Furthermore, the emphasis was to be upon training; specifically, how training might be impacted by various simulator configurations and techniques, and how such training would transfer to the aircraft. Since the research orientation was to be training, the measurement system should emphasize the most salient characteristics of the training process. In other words, there should be a close correspondence between desired training objectives and performance measures. Two key elements in the development of instructional systems are the definition of criterion-referenced objectives and the specification of performance standards. Thus, if the measurement system is to be used within the training context, it should provide information on the degree to which the behavioral objectives and performance standards are met.

Consideration was also given to the fact that there would be two users of measurement information in the ASPT—the researcher and the IP who would provide the required training. For

the researcher, it is necessary that measures are of sufficient sensitivity for evaluating relatively small effects. For the IP, it is necessary that measures are meaningful and can be readily interpreted. To whatever extent possible, measures should be designed to provide diagnostic information.

Another requirement was simplicity. Most flight simulation devices can output a relatively large number of aircraft state and control input parameters at a variety of sampling rates. There is an inherent temptation to collect all the available data. Although it may be possible to define criterion performance on many of the available parameters, the resulting number of measures would be prohibitive—especially in terms of the number of observations necessary for validation. Criterion performance should be defined only on those parameters which are critical to the successful execution of a maneuver. A parameter should be selected only if it is an essential component of a maneuver or if it has diagnostic or feedback value. Simply stated, the measurement system should reflect only the most salient characteristics of performance.

One additional requirement was that the measurement system should evaluate performance on a real-time basis. Diagnostic feedback is most effective when provided immediately after execution of a maneuver. To require extensive off-line processing of the data to arrive at performance measures would be unrealistic, except for the development of measures for hardware research. Furthermore, real-time measurement is necessary if adaptive training features are to be utilized, since variation of task difficulty is manipulated as a function of the level of performance. The necessity of real-time measurement further emphasizes the need for simplicity in developing measures of proficiency.

To summarize, four constraints were placed on the development effort at the outset: (a) at a minimum, measures should assess the degree to which behavioral objectives are met, (b) measures should be developed to provide information to two users, the researcher and the IP, (c) measures should reflect only the most salient characteristics of performance, and (d) measurement should be accomplished on a real-time basis.

Definition of Performance Measures

To guide the definition of candidate performance measures, it was assumed that superior flying performance in the aircraft or the simulator has several characteristics which are reflected by available flight parameters. These include (a) maintaining certain aircraft state parameters, such as airspeed or altitude, close to some defined criterion value, (b) avoiding excessive rates and acceleration forces so that the maneuver is executed smoothly, (c) accomplishing these objectives with the least amount of effort; that is, by minimizing control inputs, and (d) not exceeding procedural or safety limits established for the maneuver. For each of these characteristics, a candidate set of measures was defined.

Criterion-Referenced Measures. Most maneuvers may be broken down into segments for measurement purposes. During each segment, certain aircraft state parameters should be held close to some ideal, or criterion value. The amount of deviation from these ideal values provides an index of performance. The state parameters and the ideal values may change from one segment to the next, depending on how the maneuver is defined. For example, a simple turn to a heading may be broken into three steady state segments. In the first segment, the heading, altitude, and airspeed are the steady state parameters, and deviations are measured from the criterion values. During the turn, altitude, airspeed and bank are the steady state parameters. After rolling out of the turn, altitude, airspeed, and heading are the steady state parameters again, but now a new criterion value is established for heading.

The most common state parameters measured are either altitude, airspeed, heading, or bank. However, complex maneuvers occasionally contain other parameters which should be held constant during part or all of the maneuver. These maneuvers usually require that a new state parameter be computed and the deviation be measured from the computed value. For example, during a traffic pattern, the pilot should be able to determine and maintain an angle of bank in the final turn which will enable proper runway alignment during roll out. The required bank in this case must be continuously computed using the current aircraft position and heading. The bank deviation is then computed by comparing the actual bank to the computed ideal value.

Although deviations from the desired values provide an index of the amount of error at any one instant, it is necessary to summarize the information. For each parameter, both the arithmetic mean deviation and the root-mean-square (RMS) deviation are computed. In addition, a tolerance band is set for each steady-state parameter. The percentage of time during the maneuver that the deviation is above the tolerance, within tolerance, or below tolerance is computed. These time-on-tolerance measures were designed primarily for student feedback. They give the student more complete information on how well one parameter was being controlled relative to another and how often the error was either high, low, or "acceptable." Two other measures are also computed which have often been used in manual data collection pilot performance research. These are simply the maximum and minimum values for each state parameter. Thus, seven measures are computed for each parameter: (a) mean deviation, (b) RMS deviation, (c) percentage of time above tolerance, (d) percentage of time "on" tolerance, (e) percentage of time below tolerance, (f) maximum value, and (g) minimum value.

Aside from these measures continuously computed over some portion of the maneuver, single values are also recorded at key points for certain maneuvers. For example, speed at rotation and speed at gear retraction are recorded for the takeoff. Since these values are dependent on the specific maneuver, no common set of measures could be defined.

Smoothness Measures. While the state parameter deviations are the primary measure of performance, certain other measures are computed which reflect how smoothly the maneuver is executed. These measures are descriptive of the rates and accelerations of the simulated aircraft along the vertical axes and about the longitudinal and lateral axes. Pitch, roll, and heave were chosen since preliminary data indicated these axes to be the only ones delivering perceptible force cueing information. Six measures were defined: (a) RMS pitch rate, (b) RMS pitch acceleration, (c) RMS roll rate, (d) RMS roll acceleration, (e) RMS vertical velocity, and (f) RMS vertical acceleration.

Control Input Measures. The effort expended by the pilot may be determined by characteristics of the forces exerted on the control and the distances the controls are moved. Five primary flight controls were of interest: (a) elevator (Y-axis), (b) aileron (X-axis), (c) rudder, (d) throttle, and (e) trim. Since the stick was considered the primary flight control, most measures were defined to characterize its movement. For elevator and aileron control, four measures were defined: (a) RMS position (deviation from zero point), (b) RMS movement, (c) RMS power (force times movement), and (d) number of reversals. For the elevator, both mean force and RMS force were also considered of interest. For rudder control, only two measures were defined: RMS power and RMS movement. For throttle control, only one measure, RMS movement, was defined. For trim control, one measure was defined, the percentage of time the elevator force remained within some tolerance band.

Procedural/Safety Error Messages. Certain maneuvers require that the pilot perform some procedures in a specified time interval during the maneuver or else maintain the aircraft within certain safety limits. The traffic pattern is a good example of this type of maneuver. The pilot must lower the speedbrake, landing gear, and flaps at specified times during the approach. These types of procedures may be monitored in the APM system and logicals set true or false, denoting whether or

not the procedure was accomplished in the appropriate time interval. In addition, certain safety limits have been established for the complex maneuvers. In the traffic pattern, an error logical is set if the final approach is too low or too slow or if touchdown occurs at some place other than the prescribed area on the runway. Since such errors are completely dependent on the specific maneuver, no common set of measures could be defined.

Application to T-37 Maneuvers

The application of the performance measures described in the previous section required a series of steps: (a) maneuver selection, (b) maneuver segmentation, (c) definition of criteria for each segment, (d) develoapment of summary score measures, and (e) the development of performance standards.

Maneuver Selection. The intent was to select representative maneuvers from all phases of T-37 training, thereby providing a measurement capability on a continuum from t' simplest to the most complex tasks. With this capability, research studies could be accomplished on any part of the T-37 training program. Actual development efforts began with the simpler tasks and progressed through the more complex maneuvers. At the outset, only basic instrument scenarios could be developed and implemented since the ASPT visual system had not been installed. Furthermore, implementation of these scenarios represented the initial on-the-job training (OJT) for the ASPT programmers so that these simpler tasks enabled more rapid coding and debugging. After the visual system was installed, scenario development began for contact tasks. Again, the approach was to concentrate on tasks which were relatively simple and for which performance criteria were adequately specified.

Such a building block approach is contrary to previous efforts which have attempted to start at the more difficult end of the continuum. For example, efforts using adaptive math models (Connelly et al, 1974a) focused on two aerobatic tasks. Likewise, of the six tasks analyzed by Baum et al. (1973), five were aerobatic tasks. While aerobatic tasks are certainly challenging from a measurement development standpoint because of poorly defined criteria, it should be realized that aerobatics are not emphasized within T-37 training and are used primarily as "confidence building" maneuvers. The only requirement is that each maneuver be demonstrated and that the student fly each task at a "Fair" level. Oftentimes, aerobatic sorties are used to practice other contact tasks considered to be of greater importance. In retrospect, the decision to concentrate initial efforts on the more basic skills seemed a good one, since two subsequent studies failed to demonstrate a substantial amount of positive transfer for aerobatic tasks (Martin & Waag, 1978b; Woodruff, Smith, Fuller & Weyer, 1976). However, the extent to which such modest transfer was due to problems of measurement is unknown.

Maneuver Segmentation. Although maneuver execution is a continuous process, it may be conceptualized as integrated sequences of steady states and transitions. The fundamental flight attitudes, plus transitions from one attitude to another, form the conceptual segments for most maneuvers (Meyer, Loveson, Weissman, & Eddowes, 1974). The advantages of segmentation should be apparent from the previous example of the 30° turn to heading. Prior to the roll-in and after the roll-out, the desired angle of bank is zero. During the turn, however, the desired value is 30° . For the purpose of measuring deviation from desired bank angle, it is easier to divide the turn into three segments and measure the difference against a constant value for each segment, rather than generate a continuous function for the entire maneuver. Such maneuver segmentation has been utilized in most previous efforts (Baum et al, 1973; Connelly et al, 1974a, 1974b).

Although the segmentation approach appears straightforward, two problems can occur—the definition of the start/stop logic rules and the measurement of transitions. In the turn-to-heading

example, when is it appropriate to start measuring deviations from the desired 30° angle of bank? In other words, how does the computer decide that a 30° bank angle has been established? One solution might be to establish some band about 30° so that measurement begins once that region is entered. Despite the apparent reasonableness of such an approach, there are problems which may take some time to uncover. For example, it is possible for the pilot to enter a shallow bank so that scoring never begins or else to enter the tolerance band only after a significant amount of heading change has occurred. There would also be some differences as a function of the roll-in rate. The approach used in the present effort was to initiate a timer once a certain condition had been met and begin measurement once a certain amount of time had elapsed. In the turn-to-heading scenario, the timer was initiated whenever bank angle was greater than 15° . At this value, it is highly likely that the roll-in has been initiated. After 3 seconds, deviations from the desired 30° bank angle are scored. This value was derived through observation of the performance of experienced pilots. In this manner, scoring is initiated whenever the pilot should have achieved the desired bank angle.

In other instances, start/stop logic rules were based on published Air Training Command (ATC) criteria. For example, start/stop logic for the climb used the rule that altitude lead point for level-off from a climb should be 10% of vertical velocity. In other cases, voice-generated commands were used. In the steep turn, deviation from desired bank angle was computed until the command "Roll-Out" was given. Discrete events, such as raising the gear, were also used in some instances. In each case, the key ingredient was that the logic rules would unequivocally determine whether a particular segment had been entered or left. The same logic approach was also used to determine when to measure specific values, such as rotation speed or vertical velocity at touchdown.

The second difficulty, the measurement of transitions, presents even greater problems. Aside from similar start-stop logic problems, there are characteristics of transition segments that increase the difficulty of developing adequate measurements. First, some transition segments are relatively brief. For example, both the roll-in and roll-out segments of the turn-to-heading take very little time to execute. Thus, very few data can be obtained. Second, and more important, there are no readily defined criterion-referenced objectives for these transition segments. In most cases, criteria are stated very basically—e.g., to roll-in "smoothly." And third, it is unclear the extent to which performance during these transitions contributes to overall proficiency for the maneuver. It may be argued, for example, that poor performance in the transition would affect subsequent steady state performance for which adequate measurement is available. In any case, it was decided not to provide specific measurement for the individual transitions with the exception of those parameters which should be held constant (e.g., airspeed and altitude during a roll-in).

Definition of Criterion Objectives. Information on criterion-referenced objectives was obtained from several ATC publications. The primary source of information for each maneuver was ATCM 51-4, *Primary Flying Jet.* Additional information on some maneuvers was obtained in Technical Order IT-37B-1, *T-37 Flight Manual* and AFM 51-37, *Instrument Flying.* For most basic tasks, the criteria are well-defined the desired value is equal to some constant. The measurement of deviations during such steady state segments presented no problems. However, for some tasks, the desired values are constantly changing so that a simplistic approach will not work. In such cases, it was necessary to develop functional relationships wherein the desired value for a specific parameter can be determined from the current values of other parameters. For example, the desired angle of bank during the final turn can be estimated as a function of current aircraft position and heading. Connelly et al. (1974a; 1974b) have referred to these as reference functions. Such relationships are especially critical for aerobatic tasks. It should be pointed out that the functions employed in the present performance measurement system were analytically, rather than empirically, derived.

Development of Summary Score Measures. The combination of the individual measures into a meaningful, single score is perhaps the weakest point of the present measurement system—that is, if one considers such a single summary score a necessity. For one thing, it should be apparent that a single score will have no diagnostic value. It will not provide information as to which parameter is producing the greatest deviation from the ideal flightpath. Although each observed flightpath will uniquely define a performance score, each performance score does not uniquely define a particular flightpath. A given score could be obtained from an infinite number of flightpaths. For this reason, the obtained measurement provides no diagnostic information. Furthermore, there is evidence that multi-dimensional scores are more efficient in the construction of adaptive training systems (Wooldridge & Vruels, in press). Likewise, the researcher is most often interested in the specifics of an effect, rather than just the fact that an effect exists. For example, it may be desirable to know which dimension of landing performance is affected by the visual field of view.

Despite these reasons that a single summary score is of questionable value for research, both students and IPs appear to want one, if for no other reason than to compare their performance against that of their peers. Therefore, an overall time-on-target (TOT) score is computed as the maneuver progresses. This score is the percentage of time all appropriate state parameters are within tolerance simultaneously. If one or more state parameter moves out of tolerance, the TOT score will decrease. The score will not increase until all parameters are back in tolerance.

For approach/landing scenarios, such TOT summary scores were combined with instantaneous landing data to produce an overall score. Each segment was weighted according to its perceived importance by an experienced IP. Despite the fact that such total scores were not empirically derived, there is evidence to suggest they correlate to some moderate degree (.43 to .60) with IP ratings (Nataupsky, Waag, Weyer, McFadden, & McDowell, 1979).

Development of Performance Standards. Criterion-referenced objectives should define the behavioral requirements for each component of a particular flight task. Despite the existence of such "ideal" performance requirements, it is observed that they are rarely fulfilled. For example, the requirement to maintain altitude during a steep turn is rarely met. Since there usually exists some deviation about the desired values, the question becomes one of how much deviation is "acceptable." In other words, performance standards are necessary to define a range of behaviors which constitute acceptable performance. The question becomes one of how these performance standards should be generated.

Rather than relying on published ATC standards, it was decided to develop empirical standards based upon the actual performance of experienced T-37 IPs. For some of the maneuvers, a sample of 10 experienced IPs flew five repetitions. Descriptive statistics on RMS error for each parameter were computed and confidence intervals established such that experienced pilots could be expected to stay within these limits 80% of the time. These limits were then used as the tolerance bands for computing percentages of time above, within, or below limits.

Measurement System Implementation in the ASPT

Preprogramming. The ASPT Preprogramming System provides the basic framework for the APM system. It allows FORTRAN programs to be included in the ASPT software. The programs can access all parameters used in the flight simulation and perform computation in real-time, as the simulator is being flown.

The basic units of the preprogramming system are the exercise segments, which are complete programs designed to measure individual maneuvers. Each segment is composed of up to 16 separate

cases. The first case in each exercise segment, the initialization case, sets the simulator to the initial conditions selected for the maneuver. Intermediate cases contain the scoring logic, which determines the parameters to be measured during the maneuver.

To speed the programming of new exercise segments, two standard computational routines referred to as standard profiles were created. Standard Profile Number 1 (SP No. 1) computes the criterion-referenced measures presented in Table 1. All these measures, as well as error message logicals, are computed within these intermediate cases and updates at 3.75 times per second. Standard Profile Number 2 (SP No. 2) computes the smoothness and control input measures shown in Table 2. Such measures are computed by accessing a special subroutine resident in an ASPT flight module that updates at a rate of 15 times per second.[1]

The intermediate cases may also activate any of the ASPT Advanced Instructional Provisions. The student aural feedback provision is the most commonly used. When certain conditional statements in the program are satisfied, selected messages, composed of any of 189 words, are transmitted through the communication system. These messages notify the pilot when to start the maneuver, provide information during certain maneuvers, and notify the pilot with a tone when maneuver scoring is complete.

The plot provision is used during the Barrel Roll. Pitch versus heading is plotted to illustrate the nose track of the aircraft during the maneuver. The plot is displayed on a cathode ray tube (CRT) in the cockpit for review by the pilot. One other option, designed for simulator configuration research, may be activated by an intermediate case. This option automatically modified certain parameters in the math models for the motion, G-seat, or visual systems. A parameter control number may be inserted at the console keyboard to set the desired simulator configuration prior to starting a maneuver. For example, the control number 1201 may specify three-degrees-of-freedom motion, G-seat off, low visibility, and a 36° x 48° field-of-view. This option may be modified to meet the specific needs of each research project.

The final case in each exercise segment is the endpoint case. When certain conditions are met which signify that the maneuver is complete, the simulator automatically freezes. This case also transmits all the collected data to a special data file called the Student Data System (SDS). The access and control of this file is discussed under the SDS section of this report.

Up to 12 exercise segments may be grouped into a single exercise. This allows efficient sequencing from one maneuver to the next. When a maneuver terminates and automatically freezes, the operator may manually unfreeze the simulator. This will automatically sequence it to the next exercise segment and the simulator will initialize for the next maneuver.

Active Maneuver Display. Each exercise segment has a unique active maneuver display associated with it. The display may be generated on the in-cockpit CRT for student feedback and may be automatically copied for later debriefing. The display is designed to include alphanumeric titles and selected parameters available in the computer math models or in preprogramming. The percentages of high, on, and low scores, as well as the total score, are displayed for each maneuver. In addition, error messages or other information may be displayed, depending on the particular maneuver. The format for each maneuver is presented in Appendix A.

[1] The ASPT computer system has recently been updated so that SP No. 1 updates at five times per second while SP No. 2 updates at 30 times per second.

Table 1. **Standard Profile Number 1 (SP No. 1)**

Index	Measurement
1	Mean Deviation
2	Root Mean Square (RMS) Deviation
3	% High
4	% On
5	% Low
6	Maximum Deviation
7	Minimum Deviation
8	Percent Error (Bad data points)

Table 2. **Standard Profile Number 2 (SP No. 2)**

Index	Measurement	Units
1	Aileron Power	Pounds-degrees/Second
2	Aileron RMS Position	Degree
3	Aileron RMSMovement	Degrees/Second
4	Aileron Reversals	N/Second
5	Roll RMS Rate	Degrees/Second
6	Roll RMS Acceleration	Degrees/Second^2
7	Elevator Power	Pounds-Degrees/Second
8	Elevator RMS Position	Degrees
9	Elevator RMS Movement	Degrees/Second
10	Elevator Reversals	N/Second
11	Elevator Ave Trim Force	Pounds
12	Elevator RMS Trim Force	Pounds
13	Pitch RMS Rate	Degrees/Second
14	Pitch RMS Acceleration	Degrees/Second^2
15	Rudder Power	Pounds-Degrees/Second
16	Vertical Velocity RMS	Degrees/Second
17	Vertical Velocity RMS Accel	Degrees/Second
18	Throttle RMS Movement	Degrees/Second
19	Stick RMS Movement	Degrees/Second
20	Number of Samples	N

Student Data System (SDS). This system is used for the storage of data collected during each exercise segment. Certain identification information is also stored as part of the segment data record. Some of the identifier information is manually input to the SDS and the remainder is automatically input from parameters available in the computer programs. Table 3 lists the identifiers associated with each record.

Table 3. **Data Record Identifiers**

Identifier	Identifier
Student ID[a]	Segment Number
Instructor ID[a]	Initial Condition Number
Cockpit	Winds
Mission Number[a]	Segmented Elapsed Time
Date	Rating[b]
Time	Comments[b]

[a]Manually input on AIOS keyboard at start of exercise.
[b]Optional input on keyboard at termination of each segment.

The identifier information, primary performance measures, secondary performance measures, TOT scores, and error messages are transmitted for storage to a disc file immediately after a maneuver is complete. The data record is also displayed on a CRT at the console and output on a line printer for examination. Figure 1 is an example of the data record output for the Barrel Roll.

Data Retrieval and Analysis. Due to the large amount of data that could be accumulated during various research projects, it was necessary to develop a generalized retrieval system which could sort and perform some statistical analyses of data stored in the SDS. The present system is an off-line batch-type program which accepts data cards as inputs to define the data to be returned and analyzed. The data may be sorted and grouped using any of the identifiers listed in Table 3. The following statistics are provided on each group of real data variables selected: (a) sample size, (b) mean, (c) standard deviation, (d) sum X, (e) sum X^2, (f) minimum X, (g) maximum X, (h) range, (i) skewness, (j) kurtosis, and (k) correlation between any two selected variables. The retrieval and analysis program allows the researcher to make a thorough inspection or preliminary analysis of the data while a project is underway or after it is completed. Other analysis routines can be added to the program to fit the requirements of a particular research design.

III. MANEUVER DESCRIPTIONS

This section documents the manner in which each maneuver in the APM system is segmented and scored. The present system contains a cross-section of maneuvers contained in the ATC T-37 Syllabus. The primary source of information for each maneuver is ATCM 51-4, *Primary Flying Jet.* Additional information on some maneuvers may be found in Technical Order IT-37B-1, *T-37 Flight Manual,* and AFM 51-37, *Instrument Flying.*

STUDENT ID:	DORRE				
EXER SEG					
IP ID	MEHRER				
COCKPIT	B				
MIS. NO.	5				
DATE	28SEP76				
SEG NO.	43				
INIT NO.	19				
TIME	8: 8:5				
WINDS	0.0000E 00	0.0000E 00			
TURBLNCE	0.0000E 00				
	SMOOTHNESS PROFILE				
SAMPLES	3.8400E 02				
	ELEVATOR	AILERONS	RUDDER	THROTTLE	STICK
POWER	9.7121E-01	12.62673-01	1.9718E-02		
RMS POSN	1.2416E 01	7.2442E 00			
RMS MOVT	3.8679E-01	5.1825E-01	0.0000E 00	3.2229E 00	7.04793-05
REVERSAL	1.2109E 00	1.6445E 01			
% TRIMED	-3.2990E 00				
RMS TRMF	4.4992E 00				
	PITCH	ROLL	VERT VEL		
RMS RATE	4.8824E 00	1.5200E 01	8.9350E 01		
RMS ACCL	3.8354E 00	5.5028E 00	1.7148E 00		
TTLSCORE	5.6250E 01	2.0159E 02	2.5405E 02	8.8868E 01	
	MEAN ERROR	RMS ERROR	% HI	% ON	% LOW
PITCH1	1.1322E 00	3.3369 00	8.3333E 00	8.5417E 01	6.2500E 00
	7.9210E 00	-5.2834E 00	0.0000E 00		
PITCH2	-4.0600E-01	1.1325E 01	2.9167E 01	2.7083E 01	4.3750E 01
nf.12.1351E 01	-1.8730E 01	0.0000E 00			
ES TIME	0: 1:19				

Figure 1. **Data record example.**

Each maneuver is broken into segments, which are artificial distinctions for measurement purposes only. In reality, performance of all maneuvers is continuous from beginning to end. Each segment is characterized by at least one parameter that should be held constant at some ideal value. A new segment begins when the steady state parameters change or the criterion values change. A maneuver scoring profile is included with each of the following maneuver descriptions. This profile illustrates the events which mark the change from one segment to the next and the parameters that are measured in each segment. Abbreviations used and units for each parameter are presented in Table 4.

The APM system sets the simulator at an initial condition for each maneuver. The first scoring segment starts 15 seconds after the simulator is released from the starting conditions. This allows the pilot to settle down prior to starting the maneuver and it also allows sufficient time for the motion system to sequence and begin delivering full motion cues. In conjunction with this, an aural command is generated 15 seconds after release to key the pilot when to start the maneuver or perform certain tasks during the maneuver. The maneuver flow diagrams illustrate what initial conditions are set for the maneuver and what aural commands are generated during the maneuver. They also show (a) what parameters are included in the TOT score, (b) when the secondary performance measures are computed, (c) the criterion and tolerance band values for each parameter, and (d) any procedural/safety error events that are computed.

Straight and Level. This is the simplest maneuver measured by the APM system. The pilot is required to maintain altitude, airspeed, and heading constant at the initial condition values, 15,000

Table 4. **Abbreviations Used in Scoring Profile**

Abbreviation	Description
ALT	Altitude (feet)
BAN	Bank angle (degrees)
BRG	Bearing (degrees)
CD	Centerline deviation (feet)
FOW	Force on wheels (pounds)
GD	Glidepath (degrees)
GND	Groundspeed (knots)
GP	Glidepath angle (degrees)
HDG	Heading (degrees)
KIAS	Airspeed (knots)
MAX	Maximum
MEAN	Arithmetic 'mean'
MIN	Minimum
PIT	Pitch angle (degrees)
RAN	Range from runway
SB	Speedbrake
SEC	Seconds
SP No. 1	Standard Profile Number 1
SP No. 2	Standard Profile Number 2
SWT	Time simultaneously within tolerance (%)
TERM	Terminate conditions
T_0	Time when simulator is "unfrozen"
TOT	Time within Tolerance (%)
VAL	Discrete value
VC No.	Voice Command Sequence Number
WOW	Weight on wheels (pounds)

feet, 160 knots (K), and 180 degrees. The scoring profile, Table 5, illustrates that altitude, airspeed, and heading scoring begin 15 seconds after release and continue for an additional 100 seconds. At the end of the maneuver, the simulator freezes and an aural tone is generated, indicating that the maneuver is complete. The TOT score is comprised of altitude, airspeed, and heading throughout the measured portion of the maneuver.

Airspeed Increase. This maneuver requires the pilot to accelerate from low cruise airspeed, 140K, to high cruise airspeed, 190K, while maintaining constant altitude and heading. The scoring profile, Table 6, illustrates that altitude and heading are measured from the starting command to the end of the maneuver. Airspeed is not measured until after the aircraft accelerates through 186K and an additional 5 seconds have elapsed. This is a lead point for the APM system only and is not part of the maneuver as described in ATCM 51-4.

Table 5. **Straight and Level Scoring Profile**

Initial Conditions:	160 KIAS, 15000′, 180°	
Voice Commands:		
Sequence Number	Text	Start Logic
1	"Tone"	T_o ±15 sec
2	"Tone"	T_o ±115 sec

Scoring Sequence Measure	Score	Start Logic	Stop Logic	Desired Value	Tolerance
Airspeed Control[a]	Sp No. 1	T_o + 15 sec	TERM	160.0	±1.87
Altitude Control[a]	SP No. 1	T_o + 15 sec	TERM	15000.0	±31.40
Heading Control[a]	SP No. 1	T_o + 15 sec	TERM	180.0	±1.92
Elevator Force	TOT	T_o + 15 sec	TERM	0.0	±1.42
Smoothness	SP No. 2	T_o + 15 sec	TERM	—	—
Total	SWT	T_o + 15 sec	TERM	—	—

Note. — Error Flags: None
Terminate Conditions: T_o + 115 sec
[a]Denotes measures in total score.

Table 6. **Airspeed Increase Scoring Profile**

Initial Conditions:	140 KIAS, 15000′, 180°	
Voice Commands:		
Sequence Number	Text	Start Logic
1	"Increase airspeed to 190 Knots"	T_o plus 15 sec
2	"Tone"	TERM

Scoring Sequence Measure	Score	Start Logic	Stop Logic	Desired Value	Tolerance
Altitude Control[a]	SP No. 1	T_o + 15 sec	TERM	15000	±137.00
Heading Control[a]	SP No. 1	T_o + 15 sec	TERM	180.0	±12.38
Airspeed Control[a]	SP No. 1	(KIAS ≥186) + 5 sec	TERM	190.0	±1.78
Elevator Force	TOT	T_o + 15 sec	TERM	0.0	±2.26
Smoothness	SP No. 2	T_o + 15 sec	TERM	—	—
TOTAL	SWT	T_o + 15 sec	TERM	—	—

Note. — Error Flags: None
Terminate Conditions: (KIAS ≥186) + 15 sec
[a]Denotes measures in total score.

The TOT score is comprised of altitude and heading during the first part of the maneuver and then altitude, heading, and airspeed for the last 10 seconds. The pilot must maintain altitude and heading within tolerance simultaneously to improve the TOT score during the dirst part of the maneuver. The pilot must then maintain altitude, heading, and airspeed within tolerance to improve the score during the last segment of the maneuver.

Airspeed Decrease. This maneuver, which is described in Table 7, is similar to the airspeed increase. The pilot must decelerate from 190K to 140K, while maintaining constant altitude and heading. Airspeed is not measured until 5 seconds after the simulator decelerates through 144K. This lead point is used only for APM and is not part of the ATCM 51-4 maneuver description. Use of the speedbrake is optional.

Table 7. **Airspeed Decrease Scoring Profile**

Initial Conditions: 190 KIAS, 15000', 270°
Voice Commands:

Sequence Number	Text	Start Logic
1	"Reduce Airspeed to 140 Knots"	T_o + 15 sec
2	"Tone"	TERM

Scoring Sequence Measure	Score	Start Logic	Stop Logic	Desired Value	Tolerance
Altitude Control[a]	SP No. 1	T_o + 15 sec	TERM	15000.0	±45.70
Heading Control[a]	SP No. 1	T_o + 15 sec	TERM	270.0	±2.32
Airspeed Control[a]	SP No. 1	(KIAS $\leq$144) + 5 sec	TERM	140.0	±1.68
Elevator Force	TOT	T_o + 15 sec	TERM	0.0	±2.50
Smoothness	SP No. 2	T_o + 15 sec	TERM	—	—
Total	SWT	T_o + 15 sec	TERM	—	—

Note. — Error Flags:

Sequence Number	Condition	Test Logic
1	"Speed brake down"	(KIAS $\leq$144) + 5 sec

Terminate Conditions: (KIAS $\leq$144) + 15 sec
[a]Denotes measures in total score.

Turn to Heading. For this maneuver, which is described in Table 8, the pilot must turn, in the shortest direction, to a new heading given by the voice system. The new heading, either 65° or 295°, is selected by a random number generator with a probability of .5 for either heading. The turn should be accomplished using 30° bank, while maintaining airspeed and altitude constant. The new heading is not measured until 5 seconds after the simulator passes a 10° lead point for the new heading. In the event the pilot fails to turn in the shortest direction, an error message is presented.

Steep Turn. This maneuver, which is described in Table 9, requires the pilot to perform a 60° bank steep turn in either direction. The pilot should roll into the turn and roll out on the aural commands. Bank is not measured until the roll-in is started (i.e., bank is greater than 30°), plus a 5-second delay. Bank scoring is terminated when the "Roll Out" command is given 30 seconds later. Altitude and airspeed should be held constant through the maneuver.

Table 8. **Turn to Heading Scoring Profile**

Initial Conditions:	160 KIAS, 15000′, 270°	
Voice Commands:		
Sequence Number	**Text**	**Start Lobic**
1	"Turn to Heading 065/295° "	T_o + 15 sec
2	"Tone"	TERM

Scoring Sequence Measure	Score	Start Logic	Stop Logic	Desired Value	Tolerance
Airspeed Control[a]	SP No. 1	T_o + 15 sec	TERM	160.0	±2.02
Altitude Control[a]	SP No. 1	T_o + 15 sec	TERM	15000.0	±43.1
Bank Control[a]	SP No. 1	(|BANK| ≥15) + 3 sec	HDG ≥055/285	30.0	±3.23
Heading Control[a]	SP N0. 1	(HDG ≥055/285) + 5 sec	TERM	065/295	±2.79
Elevator Force	TOT	T_o + 15 sec	TERM	0.0	±1.83
Smoothness	SP No. 2	T_o + 15 sec	TERM	–	–
Total	SWT	T_o + 15 sec	TERM	–	–

Note. — Error Flags:

Sequence Number	Condition	Test Logic
1	"Wrong Direction"	0 <HDG <15

Terminate Conditions: (HDG ≥055/285) + 10 sec

[a]Denotes measures in total score.

Table 9. **Steep Turn Scoring Profile**

Initial Conditions:	160 KIAS, 15000′, 180°	
Voice Commands:		
Sequence Number	**Text**	**Start Logic**
1	"Roll-In"	To + 15 sec
2	"Roll-Out"	(|Ban| >40) + 26 sec
3	"Tone"	TERM

Scoring Sequence Measure	Score	Start Logic	Stop Logic	Desired Value	Tolerance
Airspeed Control[a]	SP No. 1	T_o + 15 sec	TERM	160.0	±4.08
Altitude Control[a]	SP No. 1	T_o + 15 sec	TERM	15000.0	±41.8
Bank Control[a]	SP No. 1	(|BAN| >40) + 6 sec	VC No. 2	60.0	±2.41
Smoothness	SP No. 2	T_o + 15 sec	TERM	–	–
Total	SWT	T_o + 15 sec	TERM	–	–

Note. — Error Flags: None

Terminate Conditions: VC No. 2 + 20 sec

[a]Denotes measures in total score.

Constant Airspeed Climb. For this maneuver, which is described in Table 10, the pilot must transition from straight-and-level flight to a climb, using 100% power, maintaining heading and airspeed constant, and leveling off at 17,000 feet. The altitude lead point for this level-off from a climb is 10% of the vertical velocity indication. The average lead point for this level-off is 150 feet. Therefore, after the simulator passes 16,850 feet, 12 seconds are allowed for level-off, and altitude measurement begins. An error notice is given if the power is not set above 98% during the climb.

Table 10. **Constant Airspeed Climb Scoring Profile**

Initial Conditions: 160 KIAS, 15000′, 180°

Voice Commands:

Sequence Number	Text	Start Logic
1	"Climb to 17000′ and level off"	T_0 + 15 sec
2	"Tone"	TERM

Scoring Sequence

Measure	Score	Start Logic	Stop Logic	Desired Value	Tolerance
Airspeed Control[a]	SP No. 1	T_0 + 20 sec	TERM	160.0	±2.67
Heading Control[a]	SP No. 1	T_0 + 20 sec	TERM	180.0	±2.42
Altitude Control[a]	SP No. 1	(ALT ≥16850) + 12 sec	TERM	17000	±36.9
Elevator Force	TOT	T_0 + 20 sec	TERM	0.0	±1.80
Smoothness	SP No. 2	T_0 + 20 sec	TERM	—	—
Total	SWT	T_0 + 20 sec	TERM	—	—

Note. — Error Flags:

Sequence Number	Condition	Test Logic
1	"Engine RPM less than 98%"	ALT ≥15500

Terminate Conditions: (ALT ≥16850) + 34 sec

[a]Denotes measures in total score.

Constant Airspeed Descent. As indicated in Table 11, the pilot must descend using 65% power and level off at 13,000 feet. Heading and airspeed should be held constant during the maneuver. The lead point philosophy is the same as that used in the climb. After the simulator passes 13,150 feet, 12 seconds are allowed for level-off and then altitude measurement begins. An error notice is given if the power is not set between 64% and 66% revolutions per minute (RPM) during the descent.

Takeoff/Approach/Landing Tasks

Takeoff. This maneuver requires the pilot to execute a takeoff from RW 30L, Williams Computer Image Generation (CIG) environment. The scoring profile is described in Table 12. The pilot should climb to 1900 feet above mean sea level (MSL) 500 feet above ground level (AGL) and 196K, while maintaining runway heading. Heading is measured from brake release to 1900 feet. Pitch attitude is measured from 75 knots until the flaps are retracted. During the climb, the pilot should maintain vertical velocity between 500 and 1000 feet per minute (FPM) and smoothly climb

and accelerate to 1900 feet and 196K. A rule-of-thumb used to adjust the climb is that for every 100 feet of climb remaining, there should be 10K of airspeed remaining. This relationship may be expressed as:

$$1900 - \text{Altitude} = (196 - \text{Airspeed})*10$$

The criterion, climb-out altitude profile may be expressed as a function of airspeed. Altitude deviation is then measured from this value:

$$\text{Climb-Out Altitude} = 1900 - (196 - \text{Airspeed})*10$$

Discrete values are collected during takeoff which indicate at what airspeed certain procedures were accomplished. In addition, TRUE/FALSE logicals are set, based on whether or not these procedures were accomplished at the proper time and in the proper sequence. Table 13 lists these values and logicals.

Takeoff and Climb on Course. This maneuver, whose profile is also described in Table 12, is the same as the takeoff up to 1900 feet MSL. At this point, the pilot should turn to intercept the 301° radial outbound from the Chandler VOR (Very High Frequency Omnidirectional Range) while continuing a tech order climb to 3000 feet MSL.

Tech Order Climb. In this task, which is described in Table 14, the pilot must maintain tech order airspeed while climbing from 2,000 feet to 15,000 feet and leveling off. Power should be set at 100% until level-off, and heading should be maintained constant throughout the maneuver. The

Table 11. **Constant Airspeed Descent Scoring Profile**

Initial Conditions: 160 KIAS, 15000', 180°
Voice Commands:

Sequence Number	Text	Start Logic
1	"Descend to 13000' and level off"	T_o + 15 sec
2	"Tone"	TERM

Scoring Sequence Measure	Score	Start Logic	Stop Logic	Desired Value	Tolerance
Airspeed Control[a]	SP No. 1	T_o + 20 sec	TERM	160.0	±2.67
Heading Control[a]	SP No. 1	T_o + 20 sec	TERM	180.0	±2.42
Altitude Control[a]	SP No. 1	(ALT ⩽13150) + 12 sec	TERM	13000.0	±36.9
Elevator Force	TOT	T_o + 20 sec	TERM	0.0	±1.80
Smoothness	SP No. 2	T_o + 20 sec	TERM	—	—
Total	SWT	T_o + 20 sec	TERM	—	—

Note. — Error Flags:

Sequence	Condition	Test Logic
1	"Engine RPM Not 65% ± 2%"	ALT ⩽14500

Terminate Conditions: (ALT ⩽13150) + 34 sec
[a]Denotes measures in total score.

Table 12. **Takeoff Scoring Profile**

Initial Conditions:	On Runway 30L at WAFB[b]				
	On Runway 30C at WAFB[c]				
Voice Commands: Sequence Number	Text	Start Logic			
1	"Tone" "Check Speed-brake Up" "Check Half Flaps"	T_o + 1 sec			
2	"Do Line up Check" "Perform takeoff"	T_o + 13 sec			
3	"Tone"	TERM			
Scoring Sequence Measure	**Score**	**Start Logic**	**Stop Logic**	**Desired Value**	**Tolerance**
Heading Deviation[a]	SP No. 1	GND >1	TERM	301.0	±1.89
Take-off Attitude[a]	SP No. 1	KIAS >75	"Flaps up"	6.10	±1.70
Climb-out Altitude[a]	SP No. 1	ALT ≥1500	TERM[b]	See Text	±83.9
Vertical Velocity[a]	SP No. 1	ALT ≥1500	TERM[b]	750	±250[d]
Course Control[a,c]	SP No. 1	TERM[1]	TERM[c]	0.0	±2.21
Tech Order Airspeed[a,c]		TERM[1]	TERM[c]	See Text	±2.30
Smoothness	SP No. 2	KIAS >75	TERM[b,c]	–	–
Rotation Airspeed	VAL	(KIAS >45)AND(PIT >3.5)	–	–	–
Lift-off Airspeed	VAL	(AS >0)AND(FOW =0)	–	–	–
Flaps-up Airspeed	VAL	"Flaps-up"	–	–	–
Gear-up Airspeed	VAL	"Gear-up"	–	–	-
Total	SWT	GND >1	TERM[b,c]	–	–

Note. — Error Flags: See Table 13

Terminate Conditions: [1](KIAS ≥196) OR (ALT ≥1900)

[2]ALT ≥3000

[a]Denotes measures in total score.

[b]Takeoff and Climb to 1900'

[c]Takeoff and Climb on Course

[d]ATC Standard

Table 13. **Takeoff Error Identifiers**

1. Right, left, or both toe brakes are depressed while rolling forward on the runway.
2. Centerline deviation is mre than 60 feet.
3. Rotation is performed with an airspeed greater than 75.
4. Airspeed is less than 80 knots at lift-off from runway surface.
5. Landing gear is up with the airspeed less than 100 knots.
6. Vertical velocity indicates the pilot is descending with the landing gear in transit or up.
7. Airspeed is less than 110 knots and the flaps are up.
8. Airspeed is greater than 135 knots and the flaps are up.

Table 14. **Tech Order Climb Scoring Profile**

Initial Conditions: 196 KIAS, 2000′, 300°

Voice Commands: Sequence Number	Text	Start Logic
1	"Level Off at 15000′" "Tech Order Airspeed"	ALT 10000
2	"Tone"	TERM

Scoring Sequence Measure	Score	Start Logic	Stop Logic	Desired Value	Tolerance
Heading Control[a]	SP No. 1	T_o + 15 sec	TERM	300.0	±2.21
Airspeed Control[a]	SP No. 1	T_o + 15 sec	TERM	(See Text)	±2.30
Altitude Control[a]	SP No. 1	(ALT ≥14800) + 12 sec	TERM	15000.0	±38.3
Elevator Force	TOT	T_o + 15 sec	TERM	0.0	±1.80
Smoothness	SP No. 2	T_o + 15 sec	TERM	–	–
Total	SWT	T_o + 15 sec	TERM	–	–

Note. — Error Flags: None
Terminate Conditions: (ALT ≥14800) No. 22 sec
[a]Denotes measures in total score.

indicated airspeed in a tech order climb should be gradually decreased 2 knots per 1,000 feet beginning at 200 knots at sea level. The criterion airspeed is computed during the maneuver and is defined by the expression:

$$\text{T.O. Airspeed} = 200 - \frac{\text{Altitude}}{500}$$

The approach to measuring altitude at level-off is similar to that described for the constant airspeed climb. After the simulator passes 14,800 feet, 12 seconds are allowed for level-off and then altitude measurement begins.

Slow Flight. This maneuver, which is described in Table 15, requires the pilot to lower the speed brake and slow to 76 knots, with full flaps and the landing gear down. After the airspeed is established, an aural command will direct the pilot to begin shallow coordination turns to approximately 20 degrees either side of the original heading. The altitude should remain constant during the maneuver. Ball deflection in the inclinometer, scored during the turns, is a measure of proper rudder coordination. After three turns are completed, or 1 minute has elapsed from the "Start Coordination Control" command, the pilot is instructed to go around, and the measurement is terminated.

Table 15. **Slow Flight Scoring Profile**

Initial Conditions: 102 KIAS, 12000', 180°

Voice Commands:

Sequence Number	Text	Start Logic
1	"Reduce Airspeed to 76 Knots"	To + 15 sec
2	"Start Coordination Control"	(KIAS <78) + 27 sec
3	"Go Around"	(KIAS <78) + 87 sec
4	"Tone"	TERM

Scoring Sequence Measure	Score	Start Logic	Stop Logic	Desired Value	Tolerance
Airspeed Control[a]	SP No. 1	KIAS <78	VC No. 3	76.0	±1.86
Altitude Control[a]	SP No. 1	KIAS <78	VC No. 3	12000.0	±49.2
Sideslip Control[a]	SP No. 1	VC No. 2	VC No. 3	0.0	±.26
Smoothness	SP No. 2	KIAS <78	VC No. 3	—	—
Total	SWT	KIAS <78	VC No. 3	—	—

Note. — Error Flags:

Sequence Number	Condition	Test Logic
1	"Configuration error, gear not down, full flaps, speed brake out"	KIAS <78
2	"Three Turns not completed in 60 sec"	VC No. 3
3	"Speedbrake Down and RPM 98% on Go-Around"	VC No. 3
4	"Gear up below 100 Knots"	KIAS <100
5	"Flaps up below 100 Knots"	KIAS <100

Terminate Conditions: KIAS 120

[a]Denotes measures in total score.

Straight-in 30L. This maneuver, described in Table 16, requires the pilot to execute a normal straight-in approach and full-stop landing. During the first part of the approach, the pilot should maintain altitude constant, maintain runway centerline, slow to 100K, and configure for landing. At 2 miles from the runway, the airspeed should be at 100K, and the simulator configured with landing gear down and full flaps. Airspeed measurement begins at this point. At 1.25 nautical miles (NM) from the runway, the pilot should intercept the 3.8° visual approach glidepath, lower the speedbrake, and begin the descent to the runway. Measurement for the glidepath portion of the approach begins at 1.25 NM and terminates at 1,000 feet from the end of the runway, to allow for flare and touchdown.

The landing score is a combination of the instantaneous heading, vertical velocity, and airspeed values at touchdown. The score is computed by the following relationship:

$$\text{Landing Score} = 100 - 2\,(77.5 - \text{KIAS}) - (302 - \text{Heading}) + .04\,(\text{Vertical Velocity}).$$

A summary score is also computed which differentially weights the final approach, glidepath, and landing scores. It should be emphasized that these weighted scores represent best "guesses" and were not derived from empirical data.

Table 16. **Straight-In Approach and Landing Scoring Profile**

Initial Conditions: 150 KIAS, 1900′, 300′, 5 mile straight-in on 30C at WAFB

Voice Commands: Sequence Number	Text	Start Logic
1	"Tone"	TERM

Scoring Sequence Measure	Score	Start Logic	Stop Logic	Desired Value	Tolerance
Final Approach Segment					
Airspeed Control[a]	SP No. 1	$T_o + 15$	(GP > -.5) OR (ALT ⩽1750)	100.0	±8.27, .73
Altitude Control[a]	SP No. 1	$T_o + 15$	(GP > -.5) OR (ALT ⩽1750)	1900.0	±69.8
Centerline Control[a]	SP No. 1	$T_o + 15$	(GP > -.5) OR (ALT ⩽1750)	0.0	±72.2
Approach Smoothness	SP No. 2	$T_o + 15$	(GP > -.5) OR (ALT ⩽1750)	–	–
Total Approach Score	SWT	$T_o + 15$	(GP > -.5) OR (ALT ⩽1750)	–	–
Glidepath Segment					
Airspeed Control[a]	SP No. 1	(GP >.5) OR (ALT ⩽1750)+1 sec	RAN ⩽1000	100.0	5.59, -.43
Glidepath Control[a]	SP No. 1	(GP >.5) OR (ALT ⩽1750)+1 sec	RAN ⩽1000	3.83	±1.0
Centerline Control[a]	SP No. 1	(GP >.5) OR (ALT ⩽1750)+1 sec	RAN ⩽1000	0.0	±51.1
Glidepath Smoothness	SP No. 2	(GP >.5) OR (ALT ⩽1750)+1 sec	RAN ⩽1000	–	–
Total Glidepath Score	SWT	(GP >.5) OR (ALT ⩽1750)+1 sec	RAN ⩽1000	–	–
Landing Segment					
Airspeed, Heading, Vertical/Velocity[a]	VAL	WOW ⩾1615	–	–	–
Total Landing Score	(See Text)	WOW ⩾1615	–	–	–

Note. — Error Flags: See Table 17
Terminate Conditions: KIAS <50
[a]Denotes measures in total score.

The error identifiers for the straight-in and landing are given in a special format to economize on display space. A single number is displayed, where each integer indicates a specific error. For example, error identifier number 10340 indicates that errors 1, 3, and 4 occurred. Error identifiers are listed in Table 17.

Touch and Go. This maneuver is a simple combination of a straight-in approach and landing followed by a takeoff. The same scoring logics are used for both the landing and takeoff phases of the maneuver. Likewise, the display formats are the same. For this reason, a detailed description is not presented.

Overhead Pattern 30L. This maneuver, illustrated in Figure 2, is divided into five separate segments: pitchout, downwind, final turn, final, and landing. A thorough analysis of the traffic pattern segments may be found in Baum, Smith, and Goebel (1973). Each segment is scored separately, and the five scores are combined to give an overall score for the maneuver. In addition, discrete error identifier numbers are computed for each segment. The error identifiers found in Table 18, use the same format as that described in the straight-in and landing.

The scoring profile is presented in Table 19. The pitchout segment starts after the pilot has initiated the roll-in. Bank angle in the pitchout may be adjusted as long as it does not exceed 60° ; therefore, a tolerance limit of 45° to 65° was selected as the acceptable range.

The pitchout segment terminates and the downwind starts when the aircraft is within 20° of the downwind heading or the pilot lowers the speedbrake. The pilot should maintain a ground track that parallels the runway or adjusts for wind drift. Since the desired ground track is not precisely specified, deviation from ground track is not measured. An error notice is given, however, if the ground track is less than 1000 feet or is greater than 4500 feet from the runway.

The downwind terminates and the final turn starts when the pilot lowers the flaps or when the aircraft is more than 1/4-mile past the end of the runway and the bank is greater than 20° . The pilot should maintain a smooth descent in the turn to insure a roll out on final at 1700 feet MSL. The ideal altitude in the turn is continuously updated according to the equation:

$$\text{Altitude} = 2500 - \frac{0}{180} *(800)$$

This relationship assumes a symmetric turn, where 0 equals the number of degrees already completed in the turn.

Table 17. **Straight-In and Landing Error Identifiers**

Final

1. Landing gear and flaps not down at 2 miles from runway.
2. Altitude less than 300 feet AGL prior to glidepath.
3. Airspeed less than 95K.
4. Speedbrake not lowered on glidepath.

Glidepath

1. Deviation from centerline greater than 80 feet.
2. Altitude less than 50 feet AGL prior to overrun, or altitude less than 100 feet AGL prior to 1/2 mile from runway.
3. Airspeed less than 95K prior to overrun.

Landing

1. Touchdown not in first 1500 feet of runway.
2. Touchdown off the side of the runway.
3. Touchdown at less than 70K.
4. Crash condition occurred at touchdown.
5. Ran off runway after touchdown

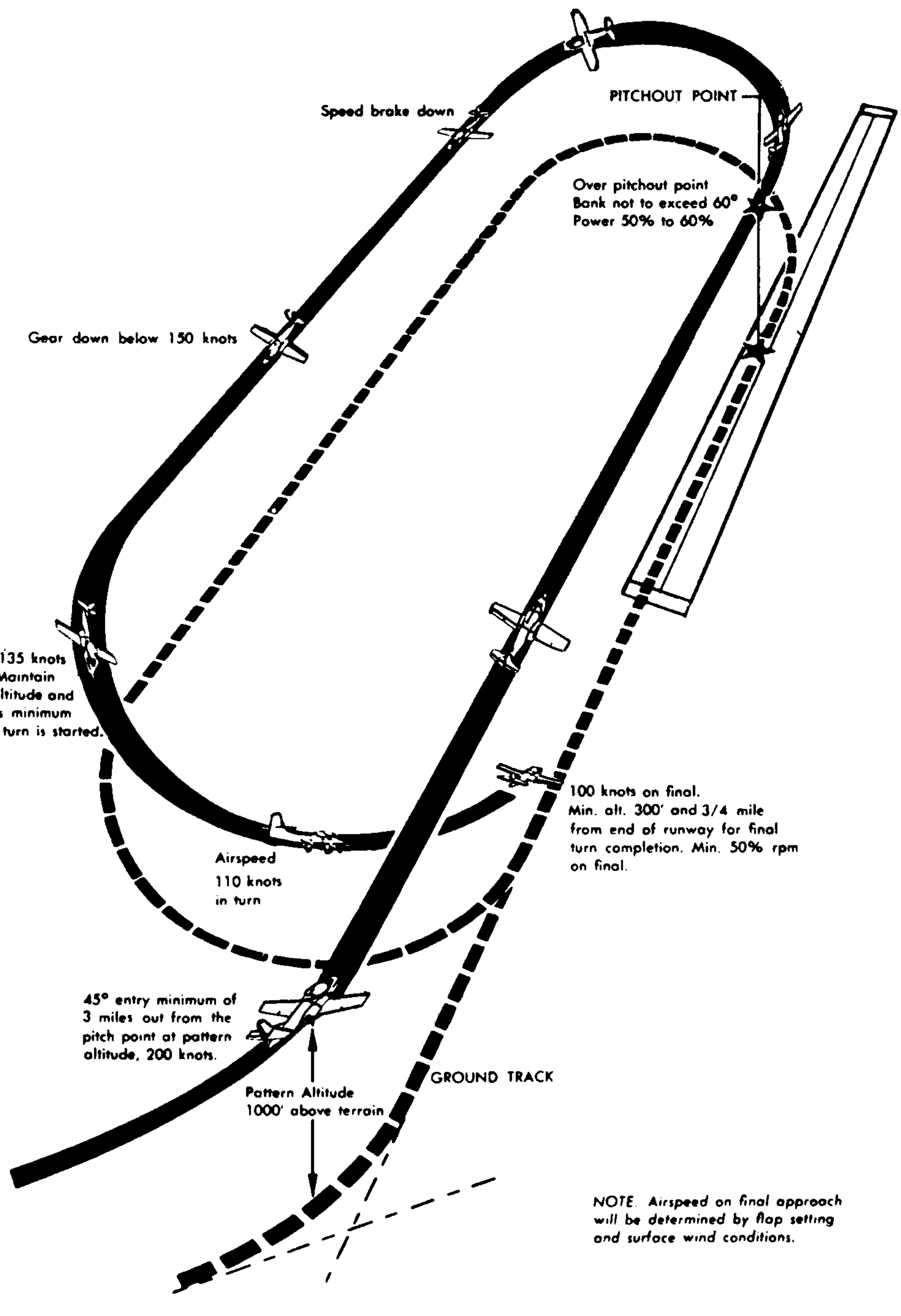


Figure 2. **Overhead pattern illustration.**

Table 18. **Overhead Pattern Error Identifiers**

Pitch Out

1. Absolute value of the bank greater than 75 degrees.
2. Altitude less than 2,300 feet or greater than 2,800 feet.
3. Average RPM of left engine less than 50% or greater than 60% .

Downwind

1. Distance from centerline less than 4,500 feet to the left or greater than 2,000 feet to the left.
2. Altitude less than 2,350 feet or greater than 2,750.
3. Airspeed less than 115 knots.
4. Landing gear not down and locked or the speedbrake not down.

Final Turn

1. Bank is less than -50 degrees.
2. Altitude less than 1,700 feet and distance from the centerline greater than 500 feet to the left.
3. Airspeed less than 105 knots and the distance from the centerline greater than 200 feet to the left.
4. Flaps are less than 80% and altitude less than 2,100 feet.
5. Range from runway threshold greater than 6,080 feet.

Final Approach to Overrun

1. Distance from the centerline greater than 80 feet on either side.
2. Altitude less than 1,430 feet or altitude less than 1,500 feet and the range from the runway threshold greater than 3,000 feet.
3. Airspeed less than 95 knots.

Touchdown

1. Range is before the runway threshold or beyond the 1,500 feet on the runway.
2. Distance from the centerline greater than 60 feet on either side at touchdown.
3. Airspeed less than 70 knots at touchdown.
4. Pilot has crashed.
5. Ran off runway after touchdown.

Table 19. Overhead Pattern Scoring Profile

Initial Conditions: 200 KIAS, 2500', 300', Runway 30L at WAFB, 3 Miles Out

Voice Commands:

Sequence 3	Text	Start Logic
1	"Tone"	TERM

Scoring Sequence

Measure	Score	Start Logic	Stop Logic	Desired Value	Tolerance
Pitch-Out Segment					
Altitude Control[a]	SP No. 1	BAN ≥20	(SB "Down") or (BAN ≤5)	2500.0	±39.9
Bank Control[a]	TOT	HDG ≤280.5	HDG ≥140.50	60.0	±15.0, + 5.0
Engine RPM	MEAN	BAN ≥20	(SB "Down") or (BAN ≤5)	–	–
Elevator Force	TOT	BAN ≥20	(SB "Down") or (BAN ≤5)	0.0	± 9.17
Smoothness	SP No. 2	BAN ≥20	(SB "Down") or (BAN ≤5)	–	–
Total	SWT	BAN ≥20	(SB "Down") or (BAN ≤5)	–	–
Downwind Segment					
Altitude Control[a]	SP No. 1	(SB "Down") or (BAN ≤5)	(FLAPS >10)or(BAN <20) and(RAN >3040')	2500.0	±38.0
Airspeed Control[a]	TOT	(SB "Down") or (BAN ≤5)	(FLAPS >10)or((BAN <20) and(RAN >3040'))	2500.0	+ 80., -0
Elevator Force	TOT	(SB "Down") or (BAN ≤5)	(FLAPS >10)or ((BAN <20) and(RAN >3040'))	120.0	+ 80.,
Smoothness	SP No. 2	(SB "Down") or (BAN ≤5)	(FLAPS >10)or((BAN <20) and(RAN >3040'))	–	–
Total	SWT	*(SB "Down") or (BAN ≤5)*	*(FLAPS >10)or((BAN <20)* and(RAN >3040'))	–	–
Final Turn Segment					
Airspeed Control[a]	SP No. 1	((FLAP >10) or ((BAN <20) and (RAN >3040')))and(ALT <2300)	(100 >CD >50)and (RAN >3040')	110.0	+ 3.2, -1.0
Bank Control[a]	SP No. 1	((FLAPS >10) or ((BAN <20) and (RAN >3040')))and(ALT <2300)	(100 >CD >50)and(RAN >3040')	(See Text)	± 5.70
Altitude Control[a]	SP No. 1	(FLAPS >10) or ((BAN <20) And(RAN >3040'))	(CD <50')or(RAN <3040')	(See Text)	±82.0
Elevator Force	TOT	(FLAPS >10)or ((BAN <20) and(RAN >3040'))	(CD <50')or(RAN <3040')	0.0	± 5.20
Smoothness	SP No. 2	(FLAPS >10) or ((BAN <20) and(RAN >3040'))	(CD <50')or(RAN <3040')	–	–
Total	SWT	(FLAPS >10) or ((BAN <20) and(RAN >3040'))	(CD <50')or(RAN <3040')	–	–
Final Approach Segment					
Glidepath Control[a]	SP No. 1	(CD <50')or(RAN <3040')	RAN ≤1000'	3.833	± .55
Centerline Control[a]	SP No. 1	(CD <50')or(RAN <3040')	RAN ≤1000'	0.0	±32.5
Airspeed Control[a]	SP No. 1	RAN <3040'	RAN ≤1000'	100	± 2.2, -1.0
Elevator Force	TOT	(CD <50')or(RAN <3040')	RAN ≤1000'	0.0	± 3.80
Smoothness	SP No. 2	(CD <50')or(RAN <3040')	RAN ≤1000'	–	–
Total	SWT	(CD <50')or(RAN <3040')	WOW >1615	–	–
Landing Segment					
Touchdown Airspeed, Heading, Vertical, Runway Postion (XY)	VAL	WOW >1615			
Summary Score	(See Text)	–	–	–	–

Note. — Error Flags: See Table 18

Terminate Condition: KIAS 50

[a]Denotes measures in total score.

The bank criterion in the turn is developed from the basic equation for the radius of a level turn:

$$R = \frac{V^2}{g \tan(B)}$$

Assuming V equals 110K, substituting 32.2 ft/sec^2 for g, and adjusting for the slight negative pitch maintained in the turn, the ideal bank in the final turn may be computed by:

$$\text{Bank} = \tan^{-1} \frac{1130.7}{(R)}$$

The radius of the turn is continuously updated in order to compute the ideal bank. This is done by assuming the current position of the aircraft is on part of a circle, of radius R, which is tangent to the extended runway centerline. The radius of this ideal turn from the current position is also adjusted to compensate for crosswinds. Therefore, the difficulty of the maneuver may be varied by changing the simulated winds.[2]

The final turn segment is completed and the final segment started when the aircraft is within 50 feet of the extended runway centerline or, as in the case of an angling final, when the range from the runway is less than 1/2 mile. The final segment and the touchdown are scored in the same manner as the straight-in approach. Summary scores are also derived in a similar manner.

Instrument Flight Tasks

Constant Rate Climb. This maneuver, which is described in Table 20, requires the student to establish a 1000-feet-per-minute climb and then off at an assigned altitude Throughout the maneuver, airspeed and heading are to remain constant. Measurement of vertical velocity begins once the student has gained 100 feet of altitude and terminates at the lead point of 100 feet below the level-off altitude. Twelve seconds after passing through the lead point, measurement of deviations from level-off altitude begins and terminates 10 seconds later.

Constant Rate Descent. The scoring logic for the constant rate descent is the same as that of the climb. The scoring profile is presented in Table 21. The student is initialized to 15,000 feet and is required to establish a constant 1000 FPM descent and then level off at 14,000 feet.

Vertical S Alpha. This maneuver consists of one rate climb and one rate descent. The pilot should establish a 1000 FPM climb or descent after the starting command. When approaching the 1000 feet altitude change, the pilot should use the recommended lead point and reverse the vertical direction. The pilot should again maintain 1000 FPM and level off when returning to the starting altitude. Heading and airspeed should be maintained constant throughout the maneuver. The value for the maximum altitude change from the starting altitude is measured when the climb or descent is reversed. An error message occurs in the event the maximum altitude change is greater than 1100 feet. The scoring profile is presented in Table 22.

[2] The criterion values for airspeed, however, are not adjusted for winds. The pilot should still attempt to fly 110K in the final turn and 100K on final.

Table 20. **Constant Rate Climb Scoring Profile**

Initial Conditions: 160 KIAS, 15000′, 180°

Voice Commands: Sequence Number	Text	Start Logic
1	"Perform Rate Climb to 16000′ and level off"	T_o + 15 sec
2	"Tone"	TERM

Scoring Sequence Measure	Score	Start Logic	Stop Logic	Desired Value	Tolerance
Airspeed Control[a]	SP No. 1	T_o + 20 sec	TERM	160.0	±2.67
Altitude Control[a]	SP No. 1	(ALT ≥15900) + 12 sec	TERM	16000.0	±36.9
Heading Control[a]	SP No. 1	T_o + 20 sec	TERM	180.0	±2.42
Vertical Velocity[a]	SP No. 1	ALT ≥15100	ALT ≥15900	1000.0	±200.0
Elevator Force	TOT	T_o + 20 sec	TERM	0.0	±1.80
Smoothness	SP No. 2	T_o + 20 sec	TERM	–	–
Total	SWT	T_o + 20 sec	TERM	–	–

Note. – Error Flags: None
Terminate Conditions: (ALT ≥15900) + 34 sec
[a]Denotes measures in total score.

Table 21. **Constant Rate Descent Scoring Profile**

Initial Conditions: 160 KIAS, 15000′, 180°

Voice Commands: Sequence Number	Text	Start Logic
1	"Perform Rate Descent to 14000′ and level off"	T_o + 15 sec
2	"Tone"	TERM

Scoring Sequence Measure	Score	Start Logic	Stop Logic	Desired Value	Tolerance
Airspeed Control[a]	SP No. 1	T_o + 20 sec	TERM	160.0	±2.67
Altitude Control[a]	SP No. 1	(ALT ≤14100) + 12 sec	TERM	14000.0	±36.9
Heading Control[a]	SP No. 1	T_o + 20 sec	TERM	180.0	±2.42
Vertical Velocity[a]	SP No. 1	ALT ≤14900	ALT ≤14100	1000.0	±200.0
Elevator Force	TOT	T_o + 20 sec	TERM	0.0	±1.80
Smoothness	SP No. 2	T_o + 20 sec	TERM	–	–
Total	SWT	T_o + 20 sec	TERM	–	–

Note. – Error Flags: None
Terminate Conditions: (ALT ≤14100) + 34 sec
[a]Denotes measures in total score.

Table 22. **Vertical S-Alpha Scoring Profile**

Initial Conditions: 160 KIAS, 15000′, 180°

Voice Commands: Sequence Number	Text	Start Logic
1	"Start the Procedure"	T_o + 15 sec
2	"Tone"	TERM

Scoring Sequence Measure	Score	Start Logic	Stop Logic	Desired Value	Tolerance
Airspeed Control[a]	SP No. 1	T_o + 15 sec	TERM 160.0	160.0	±1.51
Altitude Control[a]	SP No. 1	(|ALT - 15000| >100) + 12 sec	TERM	15000	±42.7
Heading Control[a]	SP No. 1	T_o + 15 sec	TERM	180.0	±2.25
Vertical Velocity[a]	SP No. 1	(1) |ALT- 15000| ≥100	|ALT- 15000| ≥900	1000.0	±199
		(2) |ALT- 15000| ≤900	|ALT- 15000| ≤100		
Elevator Force	TOT	T_o + 15 sec	TERM	0.0	±1.80
Min/Max Altitude	VAL	MIN/MAX ALT	—	—	—
Smoothness	SP No. 2	T_o + 15 sec	TERM	—	—
Total	SWT	T_o + 15 sec	TERM	—	—

Note. — Error Flags:

Sequence 3	Condition	Test Logic
1	"Min/Max Altitude greater than 100′ from desired"	|Max/Min(ALT)- 15000| > 1100

Terminate Conditions: (ALT-15000 ≤100) + 22 sec

[a]Denotes measures in Total Score.

Vertical S Delta. This maneuver is very similar to the Vertical S Alpha except that a 30° bank turn should be established at the same time as the initial climb or descent. When the vertical direction is reversed, at 1000 feet altitude change, the direction of turn should be reversed also. On returning to the starting altitude, the pilot should level off, roll out of the turn, and maintain heading constant. Airspeed should be maintained constant throughout the maneuver. An error message will occur if the maximum altitude change is greater than 1100 feet, or in the event a turn reversal is not executed with the climb/descent reversal. The scoring profile is presented in Table 23.

Ground Controlled Approach (GCA). The techniques and procedures required for a GCA are discussed at length in AFM 51-37 and in the T-37 flight manual. The approach in the APM system consists of an 8-mile final, glidepath, touchdown, and rollout. Aural commands are automatically generated during the approach which gives the pilot heading information to maintain the inbound course, glidepath deviation information, and general information, such as range from the runway and winds.

The measurement during the approach is very similar to that incorporated in the visual straight-in approach, and is presented in Table 24. Safety/procedural event markers indicate whether the proper configuration is established for landing or the pilot drifts an unsafe distance from course or glidepath during the approach. If these safety limits are exceeded, the pilot is automatically commanded to discontinue the approach. Error conditions are presented in Table 25.

Table 23. Vertical S-Delta Scoring Profile

Initial Conditions: 160 KIAS, 15000′, 180′

Voice Commands:

Sequence Number	Text	Start Logic
1	"Start the Procedure"	T_0 + 15 sec
2	"Tone"	TERM

Scoring Sequence Measure	Score	Start Logic	Stop Logic	Desired Value	Tolerance
Airspeed Control[a]	SP No. 1	T_0 + 15 sec	TERM	160.0	± 2.03
Altitude Control[a]	SP No. 1	($\lvert$ALT - 15000$\rvert$ ≥100) + 12 sec	TERM	15000	±32.4
Heading Control[a]	SP No. 1	($\lvert$ALT - 15000$\rvert$ ≤100) + 12 sec	TERM	!	±2.25
Bank Control[a]	SP No. 1	(1) ALT - 15000 ≤100	$\lvert$ALT - 15000$\rvert$ ≥900	30.0	±2.68
	SP No. 1	(2) $\lvert$ALT - 15000$\rvert$ ≥900	$\lvert$ALT - 15000$\rvert$ ≤100		
Vertical Velocity[a]	SP No. 1	(1) $\lvert$ALT - 15000$\rvert$ ≥100	$\lvert$ALT - 15000$\rvert$ ≥900	1000.0	±163
	SP No. 1	(2) $\lvert$ALT - 15000$\rvert$ ≤900	$\lvert$ALT - 15000$\rvert$ ≤100		
Min/Max Altitude	VAL	MIN/MAX ALT	–	–	–
Elevator Force	TOT	T_0 + 15 sec	TERM	0.0	±1.0
Smoothness	SP No. 2	T_0 + 15 sec	TERM	–	–
Total	SWT	T_0 + 15 sec	TERM	–	–

Note. — Error Flags:

Sequence Number	Condition	Test Logic
1	"Min/Max Altitude greater than 100′ from desired"	$\lvert$Max/Min (ALT)-15000$\rvert$ ≥1100
2	"Change in Turn Direction Not executed"	

Terminate Conditions: (ALT-15000 ≤100) + 22 sec

[a]Denotes measures in total score.

! Heading that occurs when (ALT -15000 <100) + 12 sec

Table 24. Ground Control Approach Scoring Profile

Initial Conditions: 160 KIAS, 2400′, 300′, Runway 30C at WAFB, 8 miles final

Voice Commands: Sequence Number	Text	Start Logic
1	"GCA Final 8 miles" "Maintain 2400′ "	T_o + sec
2	"Clear to Land Runway 30 Center"	RAN ≤7 mi
3	"Winds are below 5 Knots" or "Winds are XXX degrees at YYY Knots"	RAN ≤6.5 mi
4	"1 miles from glidepath" "Check gear down"	RAN ≤5.6 mi
5	"On glidepath" "Start Descent"	(RAN ≤5 mi)AND(GP ≥.45)
6	"Standard GCA Commands"	RAN ≤4.7 mi
7	"At GCA Minimum Altitude"	ALT ≤1525
8	"Over approach lights"	RAN ≤5 mi
9	"Tone" "GCA roll out" Change to tower frequency"	KIAS ≤60

Scoring Sequence Measure	Score	Start Logic	Stop Logic	Desired Value	Tolerance
Altitude Control[a]	SP No. 1	T_o + 15 sec	RAN ≤4.7 mi	2400.0	±32.7
Centerline Deviation[a]	SP No. 1	T_o + 15 sec	RAN ≤5mi	0.0	±87.0
Airspeed Control[a]	SP No. 1	RAN ≤4.7 mi	RAN ≤5 mi	110.0	± 2.48, -.8
Glidepath Control[a]	SP No. 1	RAN ≤4.7 mi	RAN ≤5 mi	2.5	± 1.0
Glidepath Smoothness	SP No. 2	T_o + 15 sec	RAN ≤5 mi	—	—
Landing Smoothness	SP No. 2	RAN ≤2 mi	KIAS ≤60	—	—
Airspeed, Heading, Vertical/Velocity	VAL	WOW ≥1615	—	—	—
Elevator Force	TOT	T_o + 15 sec	RAN ≤5 mi	0.0	± 1.0
Landing Score	(See Text)				
Total Score	(See Text)				

Note. — Error Flags: See Table
Terminate Conditions: VC No. 9
[a]Denotes measures in total score.

Table 25. Ground Controled Approach Error Identifiers

1. Landing Gear Up During Descent Glidepath.
2. Flaps up During Descent on Glidepath.
3. Speedbrake up During Descent on Glidepath.
4. Altitude Greater than 1525 feet During Descent on Glidepath.
5. Unsafe Centerline Deviation.
6. Airspeed Less than or Equal to 90 Knots.

Proceed Direct to VOR. This maneuver requires the pilot to proceed to a VOR. The particular VOR is selected randomly from a choice of three stations within approximately 50 miles of the initial condition. Airspeed and altitude should be held constant throughout the maneuver. After the voice command is given, the pilot should tune in the appropriate station and turn in the shortest direction toward the station. An error notice is given if the proper station is not selected within 1 minute, if a turn is not started within 1 minute after the station is tuned in, or if the turn is not in the shortest direction. Deviation from the direct course to the station is measured starting 10 seconds after the pilot rolls out heading directly towards the station. Measurement continues until station passage. Airspeed and altitude are measured throughout the maneuver. The scoring profile is presented in Table 26.

Table 26. **Proceed Direct to VOR Scoring Profile**

Initial Conditions: 190 KIAS, 20000′, 170°

Voice Commands:

Sequence Number	Test	Start Logic
1	"Go to VOR" "one, two, or three"	T_o + 15 sec
2	"Tone"	TERM

Scoring Sequence Measure	Score	Start Logic	Stop Logic	Desired Value	Tolerance[b]
Airspeed Control[a]	SP No. 1	T_o + 15 sec	TERM	190.0	±2.00
Altitude Control[a]	SP No. 1	T_o + 15 sec	TERM	20000.0	±50.0
Course Control[a]	SP No. 1	($\lvert$HDG-BRG$\rvert$ ≤10) + 5 sec	TERM	0.0	±10
Smoothness	SP No. 2	T_o + 15 sec	TERM	—	—
Total	SWT	T_o + 15 sec	TERM	—	—

Note. — Error Flags:

Sequence Number	Condition	Test Logic
1	"Proper frequency not tuned"	T_o + 75 sec
2	"Turn in Wrong Direction"	$\lvert$BAN$\rvert$ ≥15
3	"No turn initiated in 60 sec"	To No. 75 sec

Terminate Conditions: ($\lvert$HDG-BRG$\rvert$ ≤10) + 35 sec, or, "Over VOR"

[a]Denotes measures in total score.

[b]Estimated values.

erobatic Tasks

Aileron Roll. This maneuver is performed by first setting the throttle at 90% and attaining the entry airspeed at 200 to 230 knots. The roll is executed by raising the nose to 30° pitch, relaxing back pressure, and then applying aileron and coordinated rudder pressure to roll in either direction. The roll rate should remain constant and the pilot should roll out with the nose on the horizon. Since no specific roll rate is established for the maneuver, the average roll rate is computed and deviation from that average is measured. The critical discrete entry and exit parameters are also measured. They are described in the scoring profile in Table 27.

Table 27. **Aileron Roll Scoring Profile**

Initial Conditions:	160 KIAS, 15000′, 180°	
Voice Commands:		
Sequence	Text	Start Logic
2	"Start Roll"	T_0 + 15 sec
1	"Tone"	TERM

Scoring Sequence Measure	Score	Start Logic	Stop Logic	Desired Value	Tolerance
Entry Pitch,					
Airspeed,					
RPM	VAL	(KIAS >200)AND(PIT >0)	—	—	—
Exit Pitch	VAL	(PIT >0)	—	—	—
Bank In[a]	SP No. 1	(KIAS >200) AND (PIT >0)	PIT ≥20	0.0	±2.04
Bank Out[a]	SP No. 1	|BAN| ≤1.5 OR "Reversal"	PIT >0	0.0	±2.10
Roll Rate[a]	(See Text)	|BAN|≥20	|BAN|≤15	—	—
Bank in Smoothness	SP No. 2	(KIAS >200) and (PIT >0)	PIT ≥20	—	—
Roll Smoothness	SP No. 2	|BAN| ≤1.5 OR "Reversal"	PIT >0	—	—
Bank Out Smoothness	SP No. 2	|BAN| ≥20	|BAN| <15	—	—
Total Score	SWT	T_0 + 15 sec	TERM	—	—

Note. — Error Flags: None
Terminate Conditions: (PIT >0) + 5 sec
[a]Measures included in total score.

Barrel Roll. This maneuver is similar to the aileron roll. The entry throttle setting and airspeed are the same; however, the pilot should start the maneuver by turning approximately 20° to 30° to either side of a reference point near the horizon. The roll should be executed so that the nose of the aircraft describes a circle around the reference point. The maneuver is illustrated in Figure 3.

The initial condition for this maneuver is established so that the aircraft is pointed at the reference point on a heading 180° . The nose track of the aircraft may be defined as a function of pitch and heading deviation from the reference point heading. The relationship for a circular nose track may be defined as

$$H_0{}^2 = H^2 \text{ plus } P^2$$

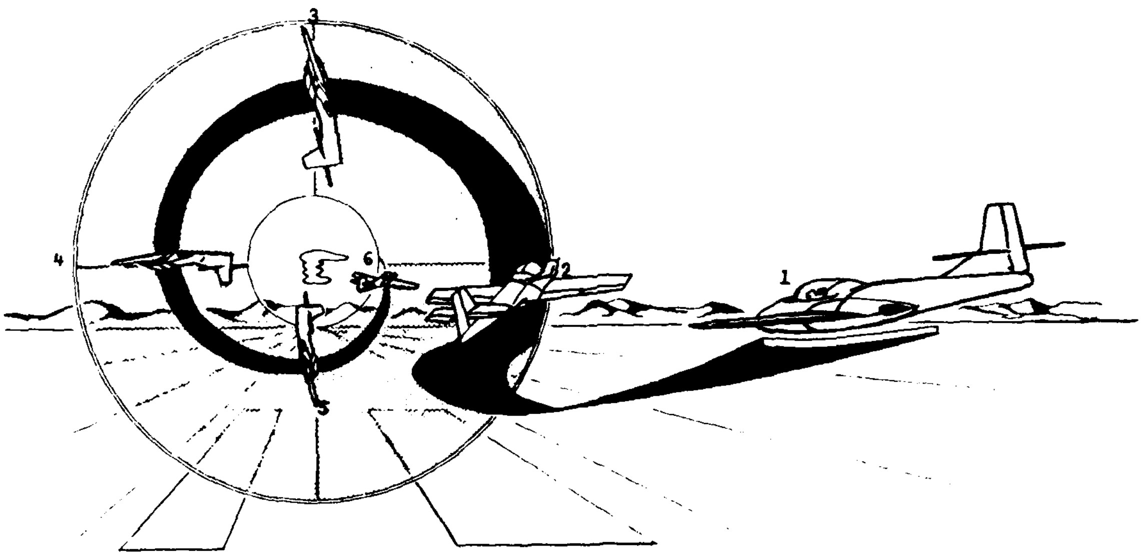
When H equals the heading deviation from the reference, H_0 equals the heading deviation at the start of the maneuver, and P equals pitch. The equation is rewritten to define the criterion pitch value as a function of heading deviation.

$$P = H_0{}^2 - H^2$$

The pitch scoring is broken into two segments, the top half of the roll and the bottom half, primarily to make the scoring more clear for the student. In addition, a plot is generated showing the actual nose track of the aircraft, versus an ideal. The scoring profile is presented in Table 28.

Loop. This maneuver, presented in Table 29, requires the pilot to execute a 360° turn in the vertical plane. The pilot should set the throttle at 100% , gain an entry airspeed of 240K to 250K, and align the aircraft with some reference on the ground, such as a straight road, prior to starting the maneuver. The back pressure is then increased to maintain a constant rate of movement of the nose.

1. Dive with nose below the reference point.
2. Wings are level just as the aircraft passes through level flight attitude to the side of the reference point.
3. Coordinate pitch and roll until directly above the point.
4. Continuous roll along circular path until inverted flight attitude.
5. Aircraft is same distance below point as it was to the side of it.
6. Roll is finished with aircraft in same position as two.



Note that this picture illustrates the apparent position of the reference point as viewed by the pilot. Contrary to what is indicated, altitude reaches its highest point in the wings-inverted position.

Figure 3. **Barrel Roll illustration.**

Table 28. **Barrel Roll Scoring Profile**

Initial Conditions:	**190 KIAS, 15000′, 270°**	
Voice Commands:		
Sequence Number	**Text**	**Start Logic**
1	"Clear to Start"	T_o + 15 sec
2	"Tone"	TERM

Scoring Sequence Measure	Score	Start Logic	Stop Logic	Desired Value	Tolerance
Entry Heading, Airspeed, Altitude, RPM	VAL	(|BAN| >20)AND(KIAS >200) AND(PIT >0)	–	–	–
Pitch Control 1 (1st half)[a]	SP No. 1	(|BAN| >20)AND(KIAS >200) AND(PIT >0)	PIT <0	(See Text)	±8.9
Pitch Control 2 (2nd half)[a]	SP No. 1	(|BAN|>20)AND(KIAS >200) AND(PIT >0)	PIT >0	(See Text)	±8.9
Smoothness	SP No. 2	(|BAN| >20)AND(KIAS >200) AND(PIT >0)	PIT >0	–	–
Total Score	SWT	(|BAN| >20)AND(KIAS >200) AND(PIT >0)	PIT >0	–	–

Note. — Error Flags: None
Terminate Conditions: (PIT >0) + 5 sec
[a]Measures included in total score.

Table 29. **Loop Scoring Profile**

Initial Conditions:	**160 KIAS, 15000′, 180°**	
Voice Commands:		
Sequence Number	**Text**	**Start Logic**
2	"Clear to Start"	T_o + 15 sec
1	"Tone"	TERM

Scoring Sequence Measure	Score	Start Logic	Stop Logic	Desired Value	Tolerance
Entry Airspeed, Altitude, RPM	VAL	(|KIAS-245| ≤10) AND(PIT >0)	–	–	–
Minimum Airspeed, G, Altitude	VAL	T_o + 15 sec	TERM	–	–
Ground Track Control[a]	SP No. 1	PIT ≥20	PIT >10	0.0	±143.0
Pitch Rate Control[a]	SP No. 1	PIT ≥20	PIT >10	13.8	±3.20
Smoothness	SP No. 2	PIT ≥20	PIT >10	–	–
Total Score	SWT	PIT ≥20	PIT >10	–	–

Note. — Error Flags: None
Terminate Conditions: (PIT >10) + 5 sec
[a]Measures included in total score.

The wing should be maintained basically level throughout the maneuver, using small adjustments with rudder and aileron, if necessary, to keep the aircraft in the vertical plane, aligned with the ground reference. A desired pitch rate was established for this maneuver by averaging the pitch rate used by experienced pilots. This value was 13.8° /sec. A theoretical groundtrack is established during the pull-up for the maneuver, and deviation from this groundtrack is then measured until the aircraft comes around to level flight again.

Split S. This maneuver is similar to the last half of a loop and is illustrated in Figure 4. The pilot should enter the maneuver with about 30° pitch, wings level, and throttles set at 90% . As airspeed decreases toward 120K, the aircraft should be rolled to the wings level inverted position. From inverted flight, the pilot should increase back pressure to the maximum possible, without high speed stalling. Back pressure should be relaxed when the half loop is completed and the aircraft resumes straight-and-level flight.

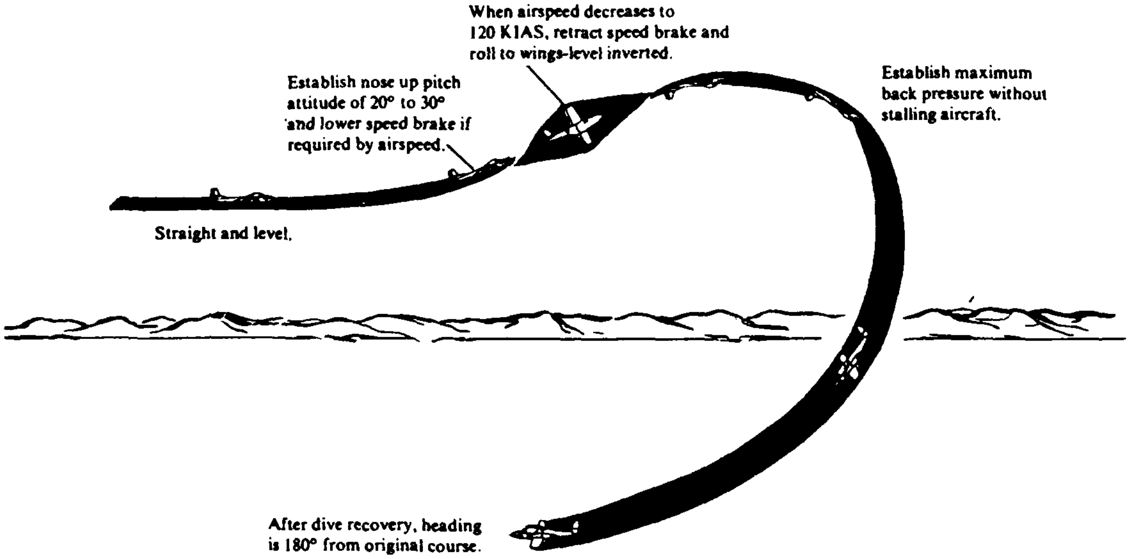


Figure 4. Split S illustration.

The scoring profile is presented in Table 30. The two primary measured parameters are bank angle and angle of attack. Deviations from a wings-level position are measured both prior to and after the roll to the inverted position. Angle of attack is measured once the inverted position is passed until -20° pitch position is passed. Discrete values are entry and exit pitch angle as well as maximum Gs.

Lazy 8. This aerobatic maneuver is described in Figure 5. It requires a combination of coordinated climbs, dives, and turns in which a Figure 8 is described by the nose track of the aircraft. Since relevant flight parameters constantly change and no continuous functions describing the desired flight path were readily available, the approach taken was to sample discrete values at

Table 30. **Split S Scoring Profile**

Initial Conditions: 160 KIAS, 15000′, 180°

Voice Commands:

Sequence Number	Text	Start Logic
1	"Clear to start"	T_o + 15 sec
2	"Tone"	TERM

Scoring Sequence Measure	Score	Start Logic	Stop Logic	Desired Value	Tolerance[b]
Bank In Control[a]	SP No. 1	PIT $\geq$3.5	KIAS $\leq$125	0.0	±3.0
Bank Out Control[a]	SP No. 1	(1) PIT $\geq$-80	PIT $\leq$-80	0.0	±3.0
		(2) PIT $\geq$-80	PIT $\geq$0		
Angle of Attach[a]	SP No. 1	(1) PIT $\geq$-80	PIT $\leq$-80	8.0	±2.0
		(2) PIT $\geq$-80	PIT <-20		
Entry Pitch, RPM	VAL	KIAS $\leq$125			
Maximum G	VAL	T_o + 15 sec	TERM	—	—
Smoothness	SP No. 2	PIT $\geq$3.5	KIAS $\leq$125	—	—
Total	SWT	PIT $\geq$3.5	PIT $\geq$0	—	—

Note. — Error Flags: None

Terminate Conditions: PIT $\geq$0

[a] *Measures included in total score.*

[b] Estimated values.

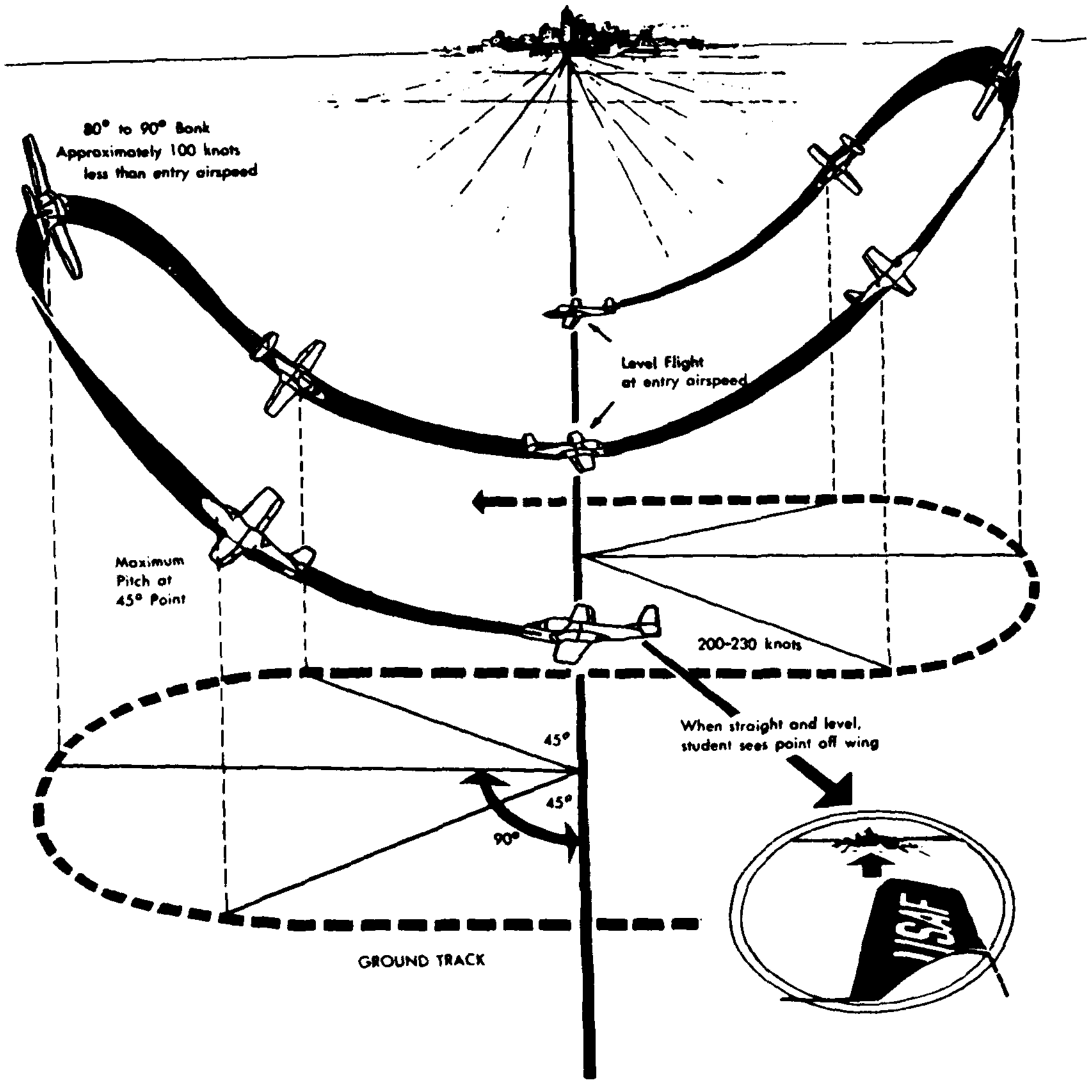


Figure 5. **Lazy 8 illustration.**

specified points throughout the maneuver. Parameters sampled include pitch, bank, airspeed, heading, and engine RPM. They are captured for each 45° of turn, thus providing a total of nine sample points. Entry values are captured whenever airspeed is greater than 200K and pitch is greater than zero. The scoring profile is presented in Table 31.

Cuban 8. A pictorial description of the Cuban 8 is presented in Figure 6. It is a modified combination of a loop and Immelmann in which the first three quarters of a loop are followed by a half roll. During the second half, the roll is usually in the opposite direction.

Table 31. **Lazy 8 Scoring Profile**

Initial Conditions:	190 KIAS, 15000', 180°	
Voice Commands:		
Sequence Number	Text	Start Logic
1	"Tone"	"KIAS 200"
2	"Tone"	TERM

Scoring Sequence Measure	Score	Start Logic	Stop Logic	Desired Value	Tolerance
PIT	VAL	*	—	—	—
Airspeed	VAL	*	—	—	—
Heading	VAL	*	—	—	—
BAN	VAL	*	—	—	—
RPM	VAL	*	—	—	—
Smoothness	SP No. 2	(PIT ≥0)AND(KIAS >200)	TERM	—	—

Note. — Error Flags: None

Terminate Conditions: PIT ≥0

*Values captured at entry (PIT ≥0) AND (KIAS >200) and at each 45° of heading change.

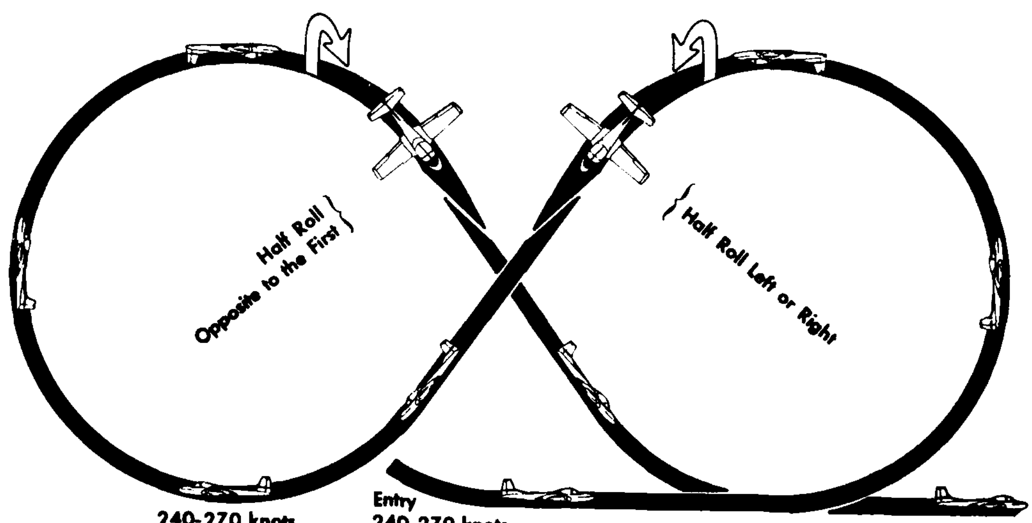


Figure 6. **Cuban 8 illustration.**

Deviations from ground track are scored continuously throughout the maneuver. Altitude, airspeed, engine RPM, and heading are captured at the entry and exit points. Entry values are captured whenever pitch is greater than zero and airspeed is greater than 240K. Exit values are captured whenever pitch is greater than -1°. Throughout the maneuver, the minimum airspeed and

maximum airspeed are recorded. The value of the pitch angle is captured whenever bank angle exceeds 87° . This occurs at roughly the mid-point of the half-roll. The present algorithm scores only the first loop of the Cuban 8. The scoring profile is presented in Table 32.

Cloverleaf. This maneuver is illustrated in Figure 7. It requires the pilot to initiate a straight pull-up similar to a loop. As 45° of pitch is reached, the pilot begins a coordinated roll toward a 90° reference point. Once on top, the remainder of the leaf is similar to the bottom of a loop.

For measurement purposes, each leaf is divided into four segments, entry to 45° pitch, roll from 45° pitch to 45° turn, roll from 45° turn to inverted position, and inverted position to level flight. For each segment, both average g and maximum g are scored. Average roll rate and g forces are also computed across the second and third segments. Discrete values are captured at selected points in the maneuver. These include: entry and exit airspeed and heading; g-loading and airspeed at the 45° pitch point; maximum pitch during the pull-up; pitch, airspeed, bank, and g loading at the 45° turn point; and, heading, bank, airspeed and g loading at the inverted position. The scoring profile for this maneuver is presented in Table 33. The present algorithm scores only the first two leaves of the maneuver.

Table 32. **Cuban 8 Scoring Profile**

Initial Conditions: 190 KIAS, 15000′, 180°
Voice Commands:

Sequence Number	Text	Start Logic
1	"Tone"	KIAS 240
2	"Tone"	TERM

Scoring Sequence Measure	Score	Start Logic	Stop Logic	Desired Value	Tolerance
Groundtrack Control[a]	SP No. 1	(PIT ≥0)AND(KIAS >240)	PIT >-1	0.0	±108.0
Entry Altitude, Airspeed, RPM, Heading	VAL	(PIT ≥0)AND(KIAS >240)	–	–	–
Exit Altitude, Airspeed, Heading	VAL	TERM	–	–	–
Maximum G's	VAL	(PIT ≥0)AND(KIAS >240)	TERM	–	–
Minimum Airspeed	VAL	(PIT ≥0)AND(KIAS >240)	–	–	–
Max Altitude	VAL	(PIT ≥0)AND(KIAS >240)	–	–	–
Pitch	VAL	|BAN| >87	–	–	–
Smoothness	SP No. 2	(PIT ≥0)AND(KIAS 240)	TERM	–	–
Total	SWT	(PIT ≥0)AND(KIAS 240)	TERM	–	–

Note. — Error Flags: None
Terminate Conditions: PIT >-1
[a]Denotes measures in total score.

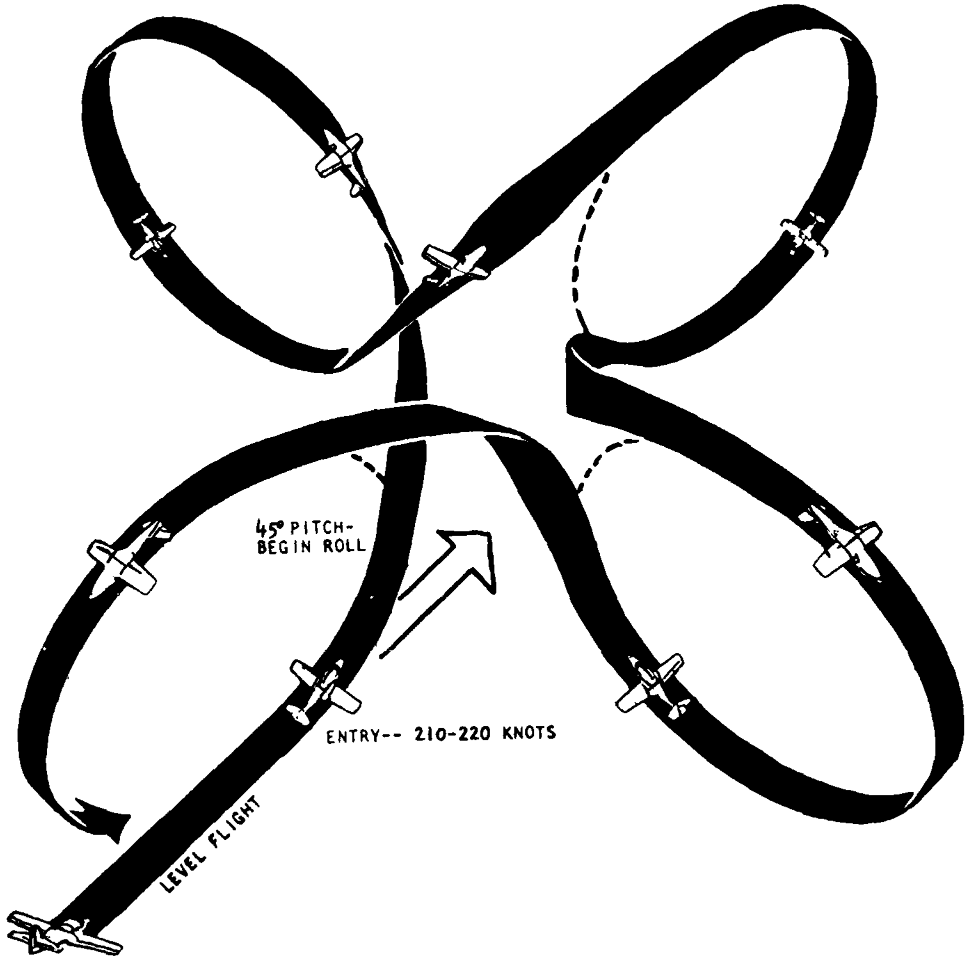


Figure 7. Cloverleaf illustration.

Table 33. **Cloverleaf Scoring Profile**

Initial Conditions: 190 KIAS, 15000′, 180°
Voice Commands:

Sequence Number	Text	Start Logic
1	"Tone"	KIAS 240
2	"Tone"	TERM

Scoring Sequence Measure	Score	Start Logic	Stop Logic	Desired Value	Tolerance
Entry Airspeed, Heading	VAL	PIT ≥10	—	—	—
Airspeed, G	VAL	PIT ≥45	—	—	—
Maximum Pitch	VAL	PIT ≥45	PIT ≥0	—	—
Pitch, Airspeed, Bank, G	VAL	(HDG-180) ≥45	—	—	—
Heading, Bank, Airspeed, G	VAL	PIT ≤0	—	—	—
Average G/Max G	MEAN/VAL	PIT ≥10	PIT ≥45	—	—
Average G/Max G	MEAN/VAL	PIT ≥45	(HDG-180) ≥45	—	—
Average G/Max G	MEAN/VAL	(HDG-180) ≥45	PIT ≤0	—	—
Average G/Max G	MEAN/VAL	PIT ≤0	—	—	—
Average Roll Rate	MEAN	PIT ≥45	PIT ≤0	—	—
Average Roll G	MEAN	PIT ≥45	PIT ≤0	—	—
Exit Airspeed, Heading	VAL	PIT ≤0	—	—	—
Smoothness	SP No. 2	VC No. 1	PIT ≤0	—	—

Note. — Error Flags: None
Terminate Conditions: PIT ≥0

Formation

Only one formation scenario was developed, fingertip. In this position, the wingman is 30′ back from the lead with approximately 3 feet of wingtip clearance. Based on the geometry of the fingertip position, the desired position coordinates (X,Y,Z) of the wingman are computed from the actual position of the lead. The scoring profile for this task is presented in Table 34.

IV. PROBLEMS AND LIMITATIONS

Maneuver Selection

At the outset, the intent was to systematically select a representative sample of maneuvers from all phases of T-37 training. With the exception of the simple instrument tasks, the actual development of the maneuvers resulted primarily from individual study requirements. Thus, the current measurement system is a reflection of T-37 maneuvers which have been used in other research investigations. It should be apparent that emphasis was placed on contact rather than on instrument tasks. In fact, the current capabilities would not support the full set of requirements for the development of an automated instrument checkride. Another deficiency is in the area of formation in that only one scenario has been written to date. One of the reasons has been that

Table 34. **Formation Scoring Profile**

Initial Conditions:	205 KIAS, 15000', 355°	
Voice Commands:		
Sequence Number	**Text**	**Start Logic**
1	"Tone"	TERM

Scoring Sequence Measure	Score	Start Logic	Stop Logic	Desire Value	Tolerance
X Position[a]	SP No. 1	T_o + 15 sec	TERM	0.0	±2.0
Y Position[a]	SP No. 1	T_o + 15 sec	TERM	0.0	±3.0
Z Position[a]	SP No. 1	T_o + 15 sec	TERM	0.0	±1.0
Minimum Lead/Lag Separation	VAL	T_o + 15 sec	TERM	–	–
Mean Lead/Lag Separation	MEAN	T_o + 15 sec	TERM	–	–
Elevator Force	TOT	T_o + 15 sec	TERM	–	–
Smoothness	SP No. 2	T_o + 15 sec	TERM	–	–
Total	SWT	T_o + 15 sec	TERM	–	–

Note. – Error Flags: None
Terminate Conditions: To + 258 sec

[a]Measures included in total score.

[b]Estimated values.

formation is very difficult to fly in the ASPT. In the first transfer of training study (Woodruff et al, 1976), the formation phase was deleted for some students because of these difficulties. In the event that the formation capabilities are improved, additional scenarios would be required.

Start-Stop Logic Rules

Some of the problems associated with the precise definition of start-stop logic rules were discussed earlier. Similarly, capturing individual system state parameters at a point in time associated with a discrete event also exemplifies some of the difficulties encountered in the development and refinement of relatively straightforward measurements. Such events as raising and lowering the landing gear, extending the speed brakes, assessing g force at a specific point in the performance of a task, and obtaining touchdown values present problems. The history associated with capturing certain parameters at the initial touchdown point will be discussed because it has presented more problems than the other cases.

The original intention was simply to capture certain state parameters (true vertical velocity, longitudinal and lateral runway position, heading, and velocity) at the moment of touchdown. The original software logic called for a logical to be set "true" at the point of touchdown. Once the logical had been set true, the algorithm called for the required parameter values to be sampled in the next consecutive sample iteration. Thus, the parameter values captured by this rule were not the initial touchdown values but the values in the next data sample.

Such logic becomes a problem partially because of a difference in sampling rate between the SDS (3.75/sec) and the iteration rate of the basic flight model (15/sec). Within a given data sample for SDS, the parameter values in basic flight are sampled at random. The combination of the data sampling rate and the original "next frame" algorithm could permit the parameter values to vary within a time delay ranging from approximately .06 to .43 second.

Once this problem was discovered (by obtaining positive true vertical velocity values at touchdown), the first remedy was to change the sampling algorithm to look backward in time one iteration from the point of setting the touchdown logical true. Conceptually, however, this solution was not adequate as it still contained the same logical deficiencies as the original algorithm. From a pragmatic viewpoint, the touchdown data were still suspect.

Upon further investigation of the data collection rules, it was discovered that the operational definition of touchdown was 1600 pounds weight on wheels, which is the requirement for activating a T-37 landing gear actuator. Subsequent data collection efforts were initiated using an ASPT feature in which seven parameters were collected at 15/second. Numerous approach and landings were performed under a variety of instructional and environmental conditions. Examination of the data revealed that up to 2 seconds could elapse between the point of the initial weight on the wheels and the time of the 1600 pounds weight. Obviously, the values of all of the parameters could change significantly during such a short time delay between initial contract and 1600 pounds. These changes could clearly alter data interpretation.

The final step in the process involved the detection of any weight on the wheels and bypassing the sampling problem associated with the difference between the SDS sample rate and the basic flight iteration rate. This involved writing a logical to have the SDS tie in with the data record (15/sec) feature in order to capture the required parameters, now programmed to include weight on wheels. However, certain conceptual problems still exist. At what point does the pilot (in this case, the IP) determine touchdown? In the ASPT, it is sometimes difficult for the pilot to determine touchdown. What about single wheel contact versus two wheel? What about the bounce situation? Informal discussions with numerous T-37 instructor pilots regarding operational definition of touchdown revealed considerable variability as to when the subjective judgement is made. Therefore, it may be necessary to further revise the logic of landing measurement techniques. This simple example exemplifies many of the problems encountered in the development of good start-stop logic rules.

Definition of Criterion Objectives

For many of the simpler tasks, the definition of criterion objectives did not present a problem. For example, if the requirement was to maintain some parameter constant, standard profile number 1 could be readily applied. However, criterion objectives for many of the more complex maneuvers could not be so easily defined. In some cases, functions were derived analytically which indicate the desired value of a certain parameter given the value of one or more other flight parameters. For some of the aerobatic tasks, only discrete captures were obtained at specific points throughout the maneuver. For example, the scenario for the Lazy 8 captures pitch, roll, airspeed, and heading at each 45 degrees of heading change. In such cases, pitch and roll values could be compared with established criteria for these specific points. However, such an approach does not provide any continuous measurement information. The approach to generation of referenced functions described by Connelly et al. (1974a; 1974b) could provide such a continuous measurement capability. In the event the current measurement system is to be enhanced, it is recommended that such an approach be attempted.

System Implementation and Operation

Since its initial development, the APM system has had numerous refinements. Many of the changes have been aimed at simplifying the operation of the system. For example, at the outset of the effort, all preprogramming was accomplished through keyboard entry at the advanced instructor operator station (AIOS). Currently, preprogramming can be accomplished in an off-line mode using remote terminals. Operation of the measurement system in conjunction with the SDS originally required a large amount of operator interaction. Currently, once an exercise (i.e., a specific sequence of maneuvers) has been defined, and header information, (i.e., student ID etc.) has been entered, the system requires the operator only to "unfreeze" the student at the beginning of each maneuver. Data storage, selection of the next task, and reinitialization are accomplished automatically. Such a capability would make the implementation of an adaptive training system in the ASPT a simple task.

The ASPT APM system was designed to provide a measurement capability for specific tasks. Thus, the development effort for each task progressed rather independently. While measurement of specific tasks in isolation from one another is reasonable for many research studies, there are other applications in which such an approach is clearly inappropriate. The creation of a full mission scenario (e.g., an instrument checkride) requires a continuous measurement capability without a freeze and reinitialization following the completion of each task within the scenario. Currently, the ASPT measurement system does not have this capability, although there is no reason it could not be developed. The implementation of such a capability would provide the opportunity to explore the degree to which mission performance in the simulator is predictive of subsequent airborne performances.

Validation

The most critical characteristic of any measure is its validity. Although several types of validity have been enumerated, the one most appropriate for the development of candidate measures of pilot performance is content validity. It demands that the most salient behavioral components be incorporated into the measure. To the extent that the measurement addresses all of the criterion-referenced objectives, the content validity will be high. It is clear that there is a relationship between the adequacy of the task definition and the validity of the resulting measurements. By taking the criterion-referenced approach to the development of performance measures in the ASPT, at least some degree of content validity was established. For the simpler tasks, the content validity appears high. However, for more complex tasks such as aerobatics, the degree of such validity is substantially reduced due to the vagueness of the criterion-referenced objectives.

Aside from content validity measures should possess some degree of empirical validity. For objective measures of pilot performance, there seem at least four criteria by which empirical validity may be established. First, these measures should successfully discriminate among pilots of different experience levels; for example, novice pilots versus IPs. Second, they should be positively correlated with concurrent measures of performance such as IP evaluations. Third, they should be sensitive to the effects of training; that is, measures should reflect increased proficiency as a function of training. And fourth, objective measures of performance should be sensitive to performance decrements resulting from adverse environmental or pilot stress factors.

Unfortunately, there has occurred no large scale validation study of the current measurement system. Nonetheless, data collected within the context of specific research studies have provided some evidence of the empirical validity of the system. As discussed earlier, Waag et al. (1975) found that the objective measures for six of the basic transition tasks flown under instrument conditions

successfully discriminated between novice and experienced pilots. Furthermore, significant correlations between the objective measures and IP ratings were obtained. In a study addressing the contributions of simulated platform motion to training effectiveness, Martin and Waag (1978a) used a unit weighting procedure to develop a single score for basic transition and takeoff/landing tasks. Using these scores, significant learning effects were demonstrated during simulator training for straight-and-level, airspeed changes, climbs/descents, slow flight, takeoffs, straight-in approaches/ landings, and overhead patterns.

Nataupsky et al. (1979) analyzed certain of the individual measures within a maneuver, and obtained significant learning effects for takeoffs, steep turns, slow flight, and straight-in approaches. Furthermore, moderate correlations between overall IP ratings and the total score currently computed in the APM system were obtained. Although no statistical tests were computed, it seems likely that the objective measures used in these two training studies would have successfully discriminated these student performances from experienced IP performance.

Irish, Grunzke, Gray, and Waters (1977) and Irish and Buckland (1978) studied the effects of various simulator configurations on the performance of experienced pilots. Two of the conditions involved various levels of turbulence and ceiling/visibility. Degraded performance as a result of these two adverse environmental conditions were reflected by the objective scores from the APM system.

Despite the fact that a large scale empirical validiation study has not been done, there is limited evidence that some of the measurement scenarios do meet some of the validity criteria. Until such an overall effort is completed, however, the APM system should be considered to consist of a candidate set of measures only. Further validation efforts would be required before the system could be implemented.

V. CONCLUSIONS AND RECOMMENDATIONS

Based on problems discussed in the previous section and on the current state of the APM system, the following recommendations are made:

1. Scenarios should be developed and implemented for additional instrument and formation tasks.

2. Alternative start-stop logic rules should be developed and evaluated for potential application.

3. Continuous functions describing the desired flight path should be developed for the aerobatic tasks.

4. The structure of the APM system should be changed to permit the implementation of continuous whole mission scenarios.

5. A systematic empirical validation of the APM system should be accomplished.

6. The applicability of current scoring procedures to other aircraft should be explored.

The current APM system in the ASPT represents one of the first attempts to develop a comprehensive, real-time measurement capability for a research simulator. Because of the training research orientation of the ASPT, the criterion-referenced approach to measurement definition was taken. Despite this emphasis, an attempt has been made to also measure some of the more salient

characteristics of control behavior as well. The result of the effort has been the development and implementation of a substantial number of scenarios for the T-37 aircraft. One question certain to arise is the degree to which these scenarios generalize to other aircraft.

Recently, the ASPT was modified to an A-10 configuration. As part of the effort, there existed a requirement to provide an objective measurement capability. Although weapons delivery scoring required new development, it was found that many of the transition tasks could be scored using the same algorithms developed for the T-37. In many instances, only the desired values changed; in others, different parameters were important. In any case, only minor changes were required. Currently, the ASPT is being modified to an F-16 configuration. Again, it is expected that only minor changes will be required to provide an objective measurement capability. Such generality points to the possibility of developing standardized measurement scenarios applicable to a wide variety of aircraft types and configurations.

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APPENDIX A: ACTIVE MANEUVER DISPLAY FORMATS

Table A1. **Straight and Level Display Format**

Straight and Level				
	Airspeed	Altitude	Heading	Overall Score
% HI	0.00	0.00	0.00	
% ON	0.00	0.00	0.00	0.00
% LOW	0.00	0.00	0.00	

Elevator Force			
	Mean	RMS	% Trimmed
	0.00	0.00	0.00

Table A2. **Airspeed Increase Display Format**

Airspeed Increase to 190 KIAS				
	Altitude	Heading	Airspeed	Overall Score
% HI	0.00	0.00	0.00	
% ON	0.00	0.00	0.00	*0.00*
% LOW	0.00	0.00	0.00	

% Trimmed: 0.00

Instructions:
1. Set Power 73% . Clean
2. Increase Airspeed to 190K after Command
3. Maintain 15M, 180 Deg

Table A3. **Airspeed Decrease Display Format**

Airspeed Decrease to 140 KIAS				
	Altitude	Heading	Airspeed	Overall Score
% HI	0.00	0.00	0.00	
% ON	0.00	0.00	0.00	0.00
% LOW	0.00	0.00	0.00	

Instructions:
1. Set Power 87% . Clean
2. Decrease Airspeed to 140K after Command
3. Maintain 15M, 270 Deg

Table A4. **Turn to Heading Display Format**

Turn to Heading of 295/065 Degrees				
	Altitude	Airspeed	Bank	Heading
% HI	0.00	0.00	0.00	
% ON	0.00	0.00	0.00	0.00
% LOW	0.00	0.00	0.00	

TURNED WRONG DIRECTION: TRUE/FALSE % TRIMMED: 0.00

Instructions:
1. Set Power 81% . Clean
2. After Command, Turn to Appropriate Heading
3. Maintain 15M, 160 Deg

Table A5. **Steep Turn Display Format**

Steep Turn				
	Altitude	Airspeed	Bank	Overall Score
% HI	0.00	0.00	0.00	
% ON	0.00	0.00	0.00	0.00
% LOW	0.00	0.00	0.00	

Instructions:
1. Set Power 81% . Clean
2. Perform 60 Deg Bank Turn, Either Direction, After Command "Roll In"
3. Maintain 15M, 160 Deg
4. Roll Out on Command

Table A6. **Constant Airspeed Climb Display Format**

Constant Airspeed Climb to 17,000′				
	Airspeed	Heading	Level Off Altitude	Overall Score
% HI	0.00	0.00	0.00	
% ON	0.00	0.00	0.00	0.00
% LOW	0.00	0.00	0.00	

POWER SETTING INCORRRECT: TRUE/FALSE % TRIMMED: 0.00

Instructions:
1. Set Power 81% . Clean
2. Climb to 17,000′ After Command
3. Maintain 180 Deg, 160K

Table A7. **Constant Airspeed Descent Display Format**

	Constant Airspeed Descent to 13,000′			
	Airspeed	Heading	Level Off Altitude	Overall Score
% HI	0.00	0.00	0.00	
% ON	0.00	0.00	0.00	0.00
% LOW	0.00	0.00	0.00	

POWER SETTING INCORRRECT: TRUE/FALSE % TRIMMED: 0.00

Instructions:

1. Set Power 81% . Clean
2. Climb to 13,000′ After Command
3. Maintain 180 Deg, 160K
4. Use Speedbrake in the Descent

Table A8. **Takeoff Display Format**

	Take Off RW 30L, Climb to 1,900′				
	Climb Out Altitude	Takeoff Attitude	Vert Vel 500-1000	Heading	Overall Score
% HI	0.00	0.00	0.00	0.00	
% ON	0.00	0.00	0.00	0.00	0.00
% LOW	0.00	0.00	0.00	0.00	

INSTRUCTIONS:	MOVING AT BRAKE RELEASE CENTERLILNE DEVIATION 0.00 ROLLED OFF RUNWAY	TRUE/FALSE
1. PERFORM NORMAL TAKEOFF AFTER COMMAND	 *ROTATION* AT 0.00	TRUE/FALSE
2. START A STRAIGHT AFTER CLIMB AFTER REACHING 1,900′ AND 196 KNOTS	LATE LIFTOFF AT 0.00 UNSAFE	TRUE/FALSE TRUE/FALSE
	GEAR AT 0.00 UNSAFE AIRSPEED WITH VVI OF 0.00	 TRUE/FALSE
	IN A DESCENT	TRUE/FALSE
% TRIMMED 0.00	*FLAPS* AT 0.00 BEFORE 110 KIAS	 TRUE/FALSE
A/S ERROR AT 1900′ : 0.00	AFTER 135 KIAS	TRUE/FALSE

Table A9. **Takeoff and Climb on Course Display Format**

Take Off RW 30C, Climb on Course Overall Score 0.00	Climb Out Altitude	Takeoff Attitude	Vert Vel 500-1000	Heading	Course	Tech Ord Climb
% HI	0.00	0.00	0.00	0.00	0.00	0.00
% ON	0.00	0.00	0.00	0.00	0.00	0.00
% LOW	0.00	0.00	0.00	0.00	0.00	0.00

INSTRUCTIONS:	MOVING AT BRAKE RELEASE	TRUE/FALSE
	CENTERLILNE DEVIATION 0.00	
	ROLLED OFF RUNWAY	
1. PERFORM NORMAL TAKEOFF AFTER COMMAND		TRUE/FALSE
	ROTATION AT 0.00	
2. AFTER TAKEOFF, INTERCEPT THE	LATE	TRUE/FALSE
CHANDLER VOR 301 DEGREE RADIAL	*LIFTOFF* AT: 0.00	
OUTBOUND.	UNSAFE	TRUE/FALSE
3. AT 1,900' AND 196 KNOTS, ASSUME A	*GEAR* AT 0.00	
TECH ORDER CLIMB	UNSAFE AIRSPEED	TRUE/FALSE
TO 3,000'	IN A DESCENT	TRUE/FALSE
% TRIMMED 0.00	*FLAPS* AT 0.00	
	BEFORE GEAR	TRUE/FALSE
A/S ERROR	BEFORE 110 KIAS	TRUE/FALSE
AT 1900' : 0.00	AFTER 135 KIAS	TRUE/FALSE

Table A10. **Tech Order Climb Display Format**

Tech Order Climb	Airspeed	Heading	Altitude	Overall Score
% HI	0.00	0.00	0.00	
% ON	0.00	0.00	0.00	0.00
% LOW	0.00	0.00	0.00	

Instructions:
1. Maintain Tech Order Airspeed
2. Level Off at 15000 Feet

Table A11. **All Slow Flight Display Format**

Slow Flight		Altitude	Airspeed	Inclinometer	Overall Score
% HI		0.00	0.00	0.00	
% ON		0.00	0.00	0.00	0.00
% LOW		0.00	0.00	0.00	

	INCOMPLETE CORD TURNS	IMPROPER CONFIGURATION	GO-AROUND SPBK DOWN	GO-AROUND EARLY GEAR	GO-AROUND EARLY FLAPS
ERRORS	TRUE/FALSE	TRUE/FALSE	TRUE/FALSE	TRUE/FALSE	TRUE/FALSE

Instructions:

1. Set Power 85% with Gear and Flaps Down
2. Maintain 100 KIAS with Speed Brake Out AFter Command
3. Slow to and Maintain 76 KIAS with Speed Brake Out After Command
4. Execute Four Coordination Turns After Command
5. Execute Go-Around After Command

Table A12. **Straight In 30L Display Format**

Straight In

	Final Approach			Glidepath		
	Altitude	Centerline Deviation	KIAS	Glidepath	Centerline Deviation	KIAS
% HI	0.00	0.00	0.00	0.00	0.00	0.00
% ON	0.00	0.00	0.00	0.00	0.00	0.00
% LOW	0.00	0.00	0.00	0.00	0.00	0.00

	Final Appr	Glidepath	Touchdown	Overall
Scores	0.00	0.00	0.00	0.00

Errors		Touchdown Values		X, Y & Gp	
F Appr	0000	KIAS	0.00	X	0.00
G Path	0000	Heading	0.00	Y	0.00
T Down	0000	V Vel	0.00	Gp	0.00

Table A13. **Overhead Pattern Display Format**

	360 OVHD Traffic Pattern			
	Pitchout: 0.00		Downwind: 0.00	
	Altitude	Bank	Airspeed	Altitude
% HI	0.00	0.00	0.00	0.00
% ON	0.00	0.00	0.00	0.00
% LOW	0.00	0.00	0.00	0.00

	Final Turn: 0.00	Final Approach: 0.00
	Bank	Airspeed
% HI	0.00	0.00
% ON	0.00	0.00
% LOW	0.00	0.00

	Pitchout	Downwind	Final Turn	Final Appr	Landing Errors
Errors	00000	00000	00000	00000	00000
	Windspeed/ Direction	0.00	0.00	Turbulence	0.00

Table A14. **Constant Rate Climb to 16,000'**

	Overall Score: 0.00			
	Airspeed	Heading	Vert Vel	Level Offqc Altitude
% HI	0.00	0.00	0.00	0.00
% LO	0.00	0.00	0.00	0.00
% LOW	0.00	0.00	0.00	0.00

% Trimmed: 0.00

Instructions:

1. Set Power 81% . Clean
2. Climb to 16,000' After Command
3. Maintain 1000 Ft/Min Rate of Climb 180 Degrees. 160 Knots

Table A15. **Constant Rate Descent Display Format**

Constant Rate Descent to 14,000′
Overall Score: 0.00

	Airspeed	Heading	Vert Vel	Level Off Altitude
% HI	0.00	0.00	0.00	0.00
% ON	0.00	0.00	0.00	0.00
% LOW	0.00	0.00	0.00	0.00

% Trimmed: 0.00

Instructions:
1. Set Power 81% . Clean
2. Climb to 14,000′ After Command
3. Maintain 1000 Ft/Min Rate of Climb 180 Degrees, 160 Knots

Table A16. **Vertical S Alpha Display Format**

Vertical S Alpha
Overall Score: 0.00

	Airspeed	Heading	Vert Vel	Altitude
% HI	0.00	0.00	0.00	0.00
% ON	0.00	0.00	0.00	0.00
% LOW	0.00	0.00	0.00	0.00

	Min/Max Altitude		Min/Max Altitude	% Trimmed
Errors	True/False	Values	0.00	0.00

Instructions:
1. Set Power 81% . Clean
2. Execute Maneuver in Either Direction After Command
3. Maintain 180 Deg, 160 KT

Operator Note: All undershoot on altitude or over 100 feet will *not* allow termination of the exercise

Table A17. **Vertical S Delta Display Format**

			Vertical S Delta		
			Overall Score : 0.00		
	Airspeed	Bank	Vert Vel	Heading	Altitude
% HI	0.00	0.00	0.00	0.00	0.00
% ON	0.00	0.00	0.00	0.00	0.00
% LOW	0.00	0.00	0.00	0.00	0.00
	Min/Max Altitude	Turn Direction		Min/Max Altitude	% Trimmed
Errors	True/False	True/False	Values	0.00	0.00

Instructions: 1. Set Power 81% . Clean
2. Execute Maneuver in Either Direction After Command
3. Maintain 160 KT

Operator Note: All undershoot on altitude or over 100 feet will *not* allow termination of the exercise

Table A18. **Ground Controlled Approach Display Format**

		GCA		
		Overall Score : 0.00		
	Altitude	Centerline Deviation	Glide Slope Deviation	Airspeed
% HI	0.00	0.00	0.00	0.00
% LO	0.00	0.00	0.00	0.00
% LOW	0.00	0.00	0.00	0.00
	Airspeed	Heading	Vert Vel	Score
Touchdown	0.00	0.00	0.00	0.00

Configuration Error		Unsafe Approach	
Gear	True/False	Glidepath	True/False
Flaps	True/False	Course	True/False
Spd Brk	True/False	Airspeed	True/False

Table A19. **Proceed Direct Display Format**

	Proceed Direct to VOR			
	VOR:		1: =PHX 115.60 2: =CHD 113.30 3: =BXK 110.60	
	Airspeed	Altitude	Course	Overall Score
% HI	0.00	0.00	0.00	
% ON	0.00	0.00	0.00	0.00
% LOW	0.00	0.00	0.00	
	Tune/Ident	Turn Dirc	Failed to Turn	
Errors	True/False	True/False	True/False	
Instructions:	1. Set Power 87% . Clean 2. Turn the correct VOR after the command 3. Turn the shortest direction to proceed direct			

Table A20. **Aileron Roll Display Format**

	Aileron Roll			
	Bank In	Roll Rate	Bank Out	Overall Score
% HI	0.00	0.00	0.00	
% ON	0.00	0.00	0.00	0.00
% LOW	0.00	0.00	0.00	
	Pitch	KIAS	RPM	
Entry Values	0.00	0.00	0.00	
Instructions:	1. Set Power 90% . Clean 2. Airspeed Between 200/230 KNOTS 3. Execute Maneuver in Either Direction			

Table A21. **Barrel Roll Display Format**

	Barrell Roll		
	Pitch Top Half	Pitch Bottom Half	Overall Score
High	0.00	0.00	
On	0.00	0.00	0.00
Low	0.00	0.00	
	Heading	KIAS	RPM
Entry Values	0.00	0.00	0.00

Instructions:
1. Set Power 81% . Clean
2. Maintain Straight and Level Until Command "Cleared to Start"
3. Execute a Left Barrell Roll Around the Mountain at 12 O'Clock

Table A22. **Loop Display Format**

Entry Val		Loop Ground Track	Pitch Rate	Overall Score
KIAS				
0.00	% HI	0.00	0.00	
ALT	% ON	0.00	0.00	0.00
0.00	% LOW	0.00	0.00	
RPM				
0.00				
	Minimum KIAS	Maximmum Altitude	Maximum G	
	0.00	0.00	0.00	

Instructios:
1. 100% Power. Clean
2. Entry KIAS: 240-250 KNOTS
3. Maintain Straight and Level Until Command "Cleared to Start:

Table A23. **Split S Display Format**

		Split S		
	Bank IN	Bank Out	Angle of Attack	Overall Score
% HI	0.00	0.00	0.00	
% ON	0.00	0.00	0.00	0.00
% LOW	0.00	0.00	0.00	
	Entry Pitch	Inverted Pitch	Entry RPM	Max G's
	0.00	0.00	0.00	0.00

Instructions:

1. Set Power 81% , Clean
2. Maintain Straight and Level until Command
3. Set appropriate power setting and enter the maneuver straight ahead without clearing

Table A24. **Lazy 8 Display Format**

		Lazy 8	
	Entry Value	First 90 Deg	180 Deg Point
Heading	0.00	0.00	0.00
Pitch	0.00	0.00	0.00
Bank	0.00	0.00	0.00
Airspeed	0.00	0.00	0.00
Core RPM	0.00	0.00	0.00
	Second 90 Deg	Exit Values	Did not make turns in alternate Directions
Heading	0.00	0.00	True/False
Pitch	0.00	0.00	
Bank	0.00	0.00	
Airspeed	0.00	0.00	
Core RPM	0.00	0.00	

Table A25. **Cuban 8 Display Format**

Cuban 8		Entry	Exit
Altitude		0.00	0.00
Airspeed		0.00	0.00
Heading		0.00	0.00
Core RPM		0.00	0.00
	Minimum Airspeed	**Maximum Altitude**	**Pitch at 90 Deg Bank**
	0.00	0.00	0.00

Table A26. **Cloverleaf Display Format**

Cloverleaf		Leaf No. 1 Value	Leaf No. 2 Value
Entry Val:	1. KIAS	0.00	0.00
	2. Heading	0.00	0.00
45 Pitch:	1. Pitch	0.00	0.00
	2. KIAS	0.00	0.00
	3. Ave G's	0.00	0.00
PK Pitch:	1. Pitch	0.00	0.00
45 Turn:	1. Pitch	0.00	0.00
	2. KIAS	0.00	0.00
	3. Bank	0.00	0.00
	4. Ave G's	0.00	0.00
Inverted:	1. Heading	0.00	0.00
	2. Bank	0.00	0.00
	3. KIAS	0.00	0.00
	4. Ave G's	0.00	0.00
	5. Ave Rol	0.00	0.00
Exit Val:	1. KIAS	0.00	0.00
	2. Heading	0.00	0.00
	3. Ave G's	0.00	0.00
Instructions:	1. 90% clean 2. Maintain S/L until command 3. Execute Rolls to left		

Table A27. **Formation Display Format**

	Formation **Overal Score: 0.00**		
	X Position	**Y Position**	**Z Position**
% HI	0.00	0.00	0.00
% ON	0.00	0.00	0.00
% LOW	0.00	0.00	0.00
	% Trim	**Mean Dist**	**Max Dist**
	0.00	0.00	0.00
	XYZ Positions from Lead Constants		
	0.00	0.00	0.00